FLOOD CONTROL

CONNECTICUT RIVER VALLEY

REPORT OF SURVEY

AND

COMPREHENSIVE PLAN

UNITED STATES ENGINEER OFFICE
PROVIDENCE, RHODE ISLAND

REPORT

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REPORT, in one volume

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WAR DEPARTMENT
United States Engineer Office
Providence, R. I.

March 20, 1937.

Subject: Report of Survey, and Comprehensive Plan, for Flood Control in the Connecticut River Valley.

To: The Chief of Engineers, U. S. Army, Washington, D. C.
(Through the Division Engineer)

SYLLABUS

The District Engineer finds that there is urgent need for flood control on the Connecticut River and tributaries, for the economic and social security of the area. He recommends a Comprehensive Plan for Flood Control consisting of twenty reservoirs, and dikes at seven cities, at an estimated total cost of $47,000,000.00.

INTRODUCTION

1. Authority.- This report is submitted pursuant to the following:

Section 6 of Rivers and Harbors Act approved August 30, 1935, Public - No. 409 - 74th Congress, which provides,

> "That the surveys authorized pursuant to section 1 of the River and Harbor Act of January 21, 1927, and House Document Numbered 308, Sixty-ninth Congress, first session, shall be supplemented by such additional study or investigation as the Chief of Engineers finds necessary to take into account important changes in economic factors as they occur, and additional stream-flow records, or other factual data."

Resolution dated March 27, 1936, by the Committee on Flood Control of the House of Representatives, which required, "That the Board of Engineers for Rivers and Harbors, ... report to this Committee at the earliest practicable date, the results of the additional studies and investigations made on the Connecticut River, to take into account important changes in economic factors, additional stream-flow records or factual data developed as a result of the recent severe flood, with a view to revising the report on this river printed as House Document No. 412, 74th Congress, 2d Session."

Section 6 of the Flood Control Act, approved June 22, 1936, Public - No. 738 - 74th Congress, which provides that,

"The Secretary of War is hereby authorized and directed to cause preliminary examinations and surveys for flood control at the following-named localities......:

Passumpsic River, Vermont

West River, Vermont between Weston and Brattleboro

Connecticut River, Massachusetts, New Hampshire, Vermont, and Connecticut."

Instructions in Paragraph 2 of 1st Indorsement, E.D. 7402-417, August 8, 1936, that,

"........a consolidated report should be submitted under the dual authority of Public No. 738, and Flood Control Committee Resolution of March 27, 1936, the report to cover the separate items in Public No. 738 (Passumpsic and West Rivers)."

2. Prior reports.- House Document No. 412, 74th Congress published the Document 308 Report, dated February 28, 1935, which set forth a comprehensive plan consisting of 33 reservoirs, with a total effective storage capacity of 931,000 acre-feet, estimated at that time to cost $41,082,000. All but one of these reservoirs were located in either Vermont or New Hampshire. The reservoirs as a system were set up in a manner that would give a maximum benefit to power, and yet allow them to function primarily for the purpose of flood protection. The net storage that would normally be available for flood control during the flood season was 444,000 acre-feet. As an initial plan, ten of the 33 reservoirs were selected and recommended for construction as a timely

measure toward flood control. The gross capacity of these ten reservoirs was set at 352,500 acre-feet, of which 84,200 acre-feet would be for flood control only. The total cost of the ten reservoirs was then estimated at $13,373,000.

A Definite Project Report, dated December 8, 1936, on the 1936 Flood Control Act Project, proposes a list of 15 reservoirs, of which a group of nine was selected and recommended as a project for immediate construction. The total flood-storage capacity of the nine reservoirs was estimated as 270,500 acre-feet. Their total cost was estimated at $13,411,400. The 15 reservoirs in the 1936 Flood Control Act Project Report are a part of the total selected for the Comprehensive Plan submitted in this report, and appear either in the Comprehensive Plan group or in the group of Alternates.

3. Existing projects - Flood Control.-

Dikes at East Hartford, Conn.- The Rivers and Harbors Act, approved August 30, 1935, Public No. 409 - 74th Congress, provides that,

> "The Secretary of War is authorized and directed to proceed with the construction of dikes, drainage gates, suitable pumping plants, and other facilities for controlling floods on the Connecticut River at East Hartford, Connecticut, pursuant to a special survey made by the district engineer at Providence, Rhode Island, supplementing the survey in House Document Number 308, Sixty-ninth Congress, First Session, and in conformity with either Plan A or Plan B designated in the report of said supplemental survey; selection of the plan to be executed shall be made by the Secretary of War with the approval of the town of East Hartford: PROVIDED, That the cost of such work shall not exceed $658,000: PROVIDED FURTHER, That the prosecution of this project shall be subject to approval by the Board of Engineers for Rivers and Harbors;"

Reservoir system in the Connecticut Valley.- The Flood Control Act approved June 22, 1936, Public No. 738 - 74th Congress, authorized the construction of a, "Reservoir system for the control of floods in the Connecticut River Valley: Construction of ten reservoirs in Vermont and New Hampshire on tributaries of the Connecticut River; plans in House Document Numbered 412, Seventy-fourth Congress, second session, as the same may be revised upon further investigation of the 1936 flood; estimated construction cost, $10,028,000; estimated cost of lands and damages, $3,344,100."

Navigation.- Rivers and Harbors Acts from time to time established a project in the Connecticut River below Hartford, Connecticut, having a channel generally 100 feet wide and 12 feet deep. The Rivers and Harbors Act approved August 30, 1935, Public No. 409 - 74th Congress, provided for the enlargement of this channel to a width generally of 150 feet and a depth of 15 feet.

4. Scope.- This report presents the results of the preliminary examination and survey for flood control of the Connecticut River, and of two of its tributaries, the West River, and the Passumpsic River. It is also a review of House Document 412, 74th Congress, for flood control, in the light of additional knowledge and data provided by the great flood of March 1936. It proposes a comprehensive plan to control flood waters for the benefit of the entire valley by providing protection for tributaries, and main river to the extent that each is practicable and economically justified. The benefits to be derived from dikes, channel improvements, and reservoirs have been studied and evaluated, and the results are stated. Summaries of data on hydrology and meteorology, geology, and flood losses, and the conclusions drawn from them are given in the report proper, together with descriptions, estimates, and economics of the proposed plan and its elements. Detailed data, descriptions, and estimates are given in the Appendix.

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DESCRIPTION OF WATERSHED.

5. Location.- The Connecticut River Basin extends from northern New Hampshire and the Province of Quebec to Long Island Sound. The eastern divide of the watershed is the White Mountains, in New Hampshire, and the lower mountains and minor elevations south of them. The western divide is the Green Mountains, extending the entire length of Vermont, the Berkshire Hills, in Massachusetts, and the minor elevations in western Connecticut. Plate 1 is a general map of the basin.

6. Size.- The greatest length of the basin is about 280 miles, and its greatest width is about 62 miles. The total drainage area is 11,260 square miles, distributed as follows: Canada, 115 square miles; New Hampshire, 3,096 square miles; Vermont, 3,911 square miles; Massachusetts, 2,712 square miles; and Connecticut, 1,426 square miles.

7. Topography.- The basin is distinctly mountainous in its northern and western areas, the ruggedness decreasing toward the south to the coastal regions, which are comparatively low and level. Elevations in the Green and White Mountains are from 3,000 to 4,500 feet above sea level, with a few peaks considerably higher. The Connecticut River flows through approximately the middle of the basin, with important tributaries entering it from both sides at irregular intervals. The tributaries are, in general, rapidly flowing mountain streams with narrow valleys and steep slopes. The valley of the main river is narrow in its upper half, widens to about 20 miles at the Massachusetts-Connecticut line, and becomes narrower again downstream to Middletown (Mile 30), where it cuts through the highlands to the east to enter the coastal lowlands.

8. Main River.- The Connecticut River rises in northern New Hampshire, near the Canadian border, flows south, and discharges into Long

Island Sound about 30 miles east of New Haven, Connecticut. Its length from First Connecticut Lake to its mouth is about 392 miles. The total fall is about 1,643 feet. For about 25 miles below the First Connecticut Lake the fall averages about 25 feet per mile. Between Miles 300 and 270 the fall is 400 feet, most of which is in the Fifteen Mile Falls reach. Below Fifteen Mile Falls to tidewater, the average fall is slightly less than two feet per mile.

9. Tributaries.- The names of the principal tributaries, their locations with reference to the main river, and the drainage areas pertaining to them are given in the following table:

TABLE 1

TRIBUTARIES, CONNECTICUT RIVER

Stream	State	Enters Connecticut River: At Mile above Mouth	Enters Connecticut River: Left or Right	Drainage Area in Square Miles: Tributary	Drainage Area in Square Miles: Connecticut River above Confluence
Nulhegan	Vt.	344.5	Right	151	651
Upper Ammonoosuc	N. H.	324.7	Left	260	945
Israel	N. H.	312.0	Left	130	1,266
Passumpsic	Vt.	279.4	Right	507	1,651
Ammonoosuc	N. H.	266.2	Left	402	2,227
Wells	Vt.	265.9	Right	99	2,629
Waits	Vt.	246.8	Right	146	2,866
Ompompanoosuc	Vt.	224.3	Right	136	3,155
White	Vt.	215.2	Right	710	3,358
Mascoma	N. H.	214.2	Left	195	4,068
Ottauquechee	Vt.	210.2	Right	223	4,302
Sugar	N. H.	195.3	Left	274	4,674
Black	Vt.	183.1	Right	197	5,034
Williams	Vt.	176.4	Right	117	5,263
West	Vt.	149.2	Right	423	5,744
Ashuelot	N. H.	139.8	Left	420	6,247
Millers	Mass.	126.0	Left	390	6,741
Deerfield	Mass.	119.1	Right	665	7,174
Chicopee	Mass.	80.4	Left	724	8,303
Westfield	Mass.	75.0	Right	520	9,075
Scantic	Conn.	59.5	Left	113	9,716
Farmington	Conn.	57.1	Right	613	9,835
Salmon	Conn.	17.8	Left	152	10,927

10. Geology.- The valley of the main river, and, to a considerable extent, the valleys of many of the tributaries have been covered by glaciers. Since retreat of the glacier, streams have been actively engaged in sweeping out the large accumulations of alluvial and glacial debris. In cutting through these deposits, the rivers have developed new channels above the earlier and deeply buried rock gorges. The present drainage system is substantially the same as that developed in past geologic ages, although the rivers now occupy channels above and to one side of the older channel. These facts help to explain the similarity in many of the valley-rock profiles, and also repetition of conditions where rock is close to the surface on one valley wall and deeply buried on the other. The basic topographic character of the watershed was formed chiefly by pre-glacier erosion of complex geologic formations, the results of which are evident in many of the more rugged features. Other less rugged but nevertheless prominent features are the results of glacial action, particularly the widespread glacial deposits, of which the alluvial outwash, glacial-lake deposits, and glacial till are of special interest in connection with the project under consideration.

11. Rocks.- The rocks are largely intrusive granite, shist, and gneiss. The schists are metamorphosed shales, sandstones, and limestones, are complexly folded, and, in addition, contain constituents of igneous origin. These rocks are essentially hard, impermeable and insoluble, except where weathered and fractured near the surface. Investigations completed so far do not indicate any unusual behavior or construction hazard which would greatly affect the proposed designs and estimates.

12. Alluvial outwash deposits.- Great quantities of sand, gravel, rock flour, and boulders were deposited by the glacier during its retreat. In the deposits thus formed, layers of sand or gravel pinch out and change in quality along their lateral extent, and they are overlapped by other

layers, which differ from them sufficiently to form a succession of beds. The whole assemblage forms a variably assorted deposit, and, where these form abutments, the question of permeability is of importance. The wide range in textural characteristics, exhibited by these deposits, makes them especially adapted for hydraulic construction.

13. Glacial-lake deposits.- During the glacial retreat, several large glacial lakes were formed in the main and tributary valleys. The sediments in the lake deposits thus formed are of exceedingly fine texture, ranging from fine sand to rock flour and clay. In some areas these materials accumulated to form deposits of great thickness. Where practicable to use them, these deposits provide impervious embankment material.

14. Glacial till.- Glacial till, consisting of ill-sorted deposits of rock flour, sand, rock fragments and boulders, derived largely from ice abrasion and transportation, is widely distributed throughout the watershed. It is generally very compact, relatively impervious, and stable. Till often directly overlies rock, and, in turn, is often overlain by outwash or lake deposits.

15. Climate. - Long, cold winters, and comparatively short summers characterize the climate of the Connecticut River Basin. The average annual temperature is about 48 degrees Fahrenheit in the southern areas, and about 41 in the northern areas, with temperatures of record as low as 40 degrees below zero in the northern sections, and 20 degrees below zero in the coastal regions. In all seasons the weather is subject to frequent and rapid changes. The area is a focal point for many of the cyclonic conditions affecting the eastern part of the United States.

16. Population.- The population of the basin was 1,228,390 in 1930. The populations of the principal cities were: Hartford, Connecticut, 164,000; New Britain, Connecticut, 68,000; Springfield, Massachusetts, 150,000; Chicopee, Massachusetts, 44,000; Holyoke,

Massachusetts, 57,000.

17. Industries.- The Connecticut River Basin, particularly the southern part in Connecticut and Massachusetts, is an industrial area of national importance. The more important industries are the manufacture of machinery, electrical goods, tools, metal products, textiles, and paper. Forest and quarry products are important items in the upper basin. The value of the total industrial output of the basin approximates one billion dollars ($1,000,000,000) annually. The principal industrial centers are Hartford, in Connecticut, and Springfield, Chicopee, and Holyoke, in Massachusetts.

18. Agriculture.- The area in farm lands in the basin in 1929 was 3,500,000 acres. The acreage under cultivation has been decreasing during recent years. The principal agricultural products are forage crops, vegetables, fruits, dairy and poultry products, and in Connecticut and Massachusetts tobacco is an important crop. The annual value of the farm products of the basin approximates $65,000,000.

19. Transportation facilities.- Main and branch-line railroads follow the Connecticut River and many of its tributaries, and are adequate for all reasonable needs. The highway systems are well developed throughout the area, and are being steadily extended and improved. Commercial navigation is limited to the Connecticut River below Hartford.

20. Present development of water resources.- Existing reservoirs, and those under construction, or proposed, which have flood-control value in the basin, are listed in Paragraph 63. In addition to the storage reservoirs listed, there are about 63 hydroelectric developments distributed throughout the basin. The developments have pondage in various amounts, but their effect upon flood flows cannot be established.

21. Relation of shape of watershed to floods.- The flood-causing storms usually travel across the territory under consideration in a

north-northeasterly direction, at a speed of from 150 to 200 miles per day. The Connecticut River Watershed being long and narrow, and lying practically north and south, is traversed diagonally, therefore, by these storms, with the result that the peak of the storm will cross the watershed generally in less than one day. This, together with the fact that the flow of the river is in the opposite direction to the course of the storm, combines to make the effects of the storm less severe and of shorter duration than might be expected from storms of equal intensity under different conditions.

22. Maps and profiles.- The locations of the reservoirs considered in this project, and their drainage areas, are shown on a map of the Connecticut River Watershed, included herewith and designated Plate I. The relation of the reservoirs in elevation is shown on the profiles of the main river and tributaries, designated Plate II.

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(Report continued on following page)

HYDROLOGY AND METEOROLOGY

Rainfall and Run-Off

23. Precipitation.- The average annual precipitation in the Connecticut River Basin is fairly well established by the precipitation records at 14 stations, with periods of duration of approximately 34 years. It varies from about 45 inches in the southern portion to about 36 inches in the northern portion, with the exception of the mountain peaks of Vermont and New Hampshire, where it is as high as 60 inches for relatively small areas. That part of the precipitation which falls as snow varies from about 35 inches of snow in the southern portion to 60 inches in the northern portion.

24. Characteristics of storms.- The magnitude of intense storms of the same duration and frequency of occurrence varies in the same direction as the mean annual precipitation. It is to be expected therefore that on the average the southern portion of the basin will receive slightly greater storms than the northern portion. However, any single storm in its distribution over the basin may be entirely independent of the probable relation. The possible and probable times of occurrence and also the path of an intense storm are functions of the origin of the storm. Those that occur over New England fall into two general classes, continental storms and tropical hurricanes. The continental storms, which originate over the United States or southwestern Canada, are by far the more frequent. These storms occur in every season of the year, although they are somewhat more numerous in December and January than during the summer months. They may originate in any section of the country, or on the West Coast, and move in a general easterly and northeasterly direction. The second class of storm that affects New England, the tropical hurricane, may be expected in any month from May to December, although by

far the greater number occur in August, September, and October. These storms, originating over the Atlantic Ocean, including the Caribbean Sea and the Gulf of Mexico, usually move in a westerly or northwesterly direction, often recurving to the northeast. They seldom reach New England with destructive force, but when they do, excessive precipitation occurs.

25. Run-off - General data.- There is a wide range between the minimum and maximum run-off of all parts of the Connecticut River Basin. The minimum values, corrected for existing storage, are approximately 0.2 cubic foot per second per square mile. The maximum values range from 30 cubic feet per second per square mile on the entire Basin to more than 200 cubic feet per second per square mile on the smaller tributaries. The average mean annual run-off is approximately 1.7 cubic feet per second per square mile. For the upper Connecticut River and the northern tributaries the run-off per square mile is, in general, greater than for the main river in its lower reaches. The average per cent of rainfall that appears as run-off is about 60 per cent. The heaviest monthly run-off occurs during March, April, and May in the lower valley and about a month later in the upper mountain areas. Low flows in the lower basin generally occur in the Fall months, but in the upper areas the winter months have the lowest run-off, owing principally to snow and the freezing of small mountain streams. These data are fairly well established by the records of 46 United States Geological Survey gaging stations in the Basin, of which 21 have been in operation 20 years or longer, and also are augmented by the records of municipal, utility, and private agencies.

26. Flood run-off.- Run-off of flood proportions is a function of the intensity and duration of the rainfall and the area covered by it, the degree of prior saturation of the ground, the depth and density of

the snow cover, if any, the temperature of the air and the ground, and the shape and topography of the watershed. It is known that rainfall alone can produce severe floods at any time of the year. Although notable exceptions have occurred, it is to be expected that the per cent of run-off from intense storms will be greater than the average annual value of 60 per cent. This can be true even during the summer season if there has been sufficient rainfall preceding the storms in question. The duration of the rainfall is an important element principally in producing floods on the larger drainage areas. The rational method of determining run-off from rainfall assumes that the maximum discharge at any station occurs when all portions of the watershed above it are contributing to the discharge at that station. This concentration period varies in the Connecticut River Basin from one-half day on the smallest tributaries to four and one-half days at Hartford. Therefore, the intense storms of short duration may cause floods on the tributaries and lesser floods at Hartford, but when storms of sufficient magnitude approach in duration the concentration period at Hartford, it is possible for severe floods to occur.

27. Effect of snow cover.- Although snow cover may act to alleviate spring floods, it usually intensifies them. If the ground is frozen and the air is warm, the run-off from a minor rain may be augmented sufficiently by melting snow to cause a major flood. Conversely, if the ground is not frozen and the temperature of the air is low, the snow may act as a sponge to retain temporarily a rainfall of considerable proportions and to release it over an extended period into surface and groundwater run-off. It has been stated that storms of the same frequency are lesser in their intensity in the northern part of the Basin than in the southern part. However, the potential increase in flood run-off from snow cover varies in the opposite direction. Therefore, the net effect

should be compensating and should tend to make the probable volume of flood run-off more nearly equal for all parts of the Basin.

28. Influence of shape and topography.- The shape and topography of the watershed affect principally the concentration period. The Connecticut Basin is long and narrow, with tributaries entering the main river from both sides at irregular intervals. It was found from a detailed study of the formation of the flood hydrograph in the middle and lower Connecticut River that the run-off from the area above Fifteen Mile Falls is retarded, owing to the elongated shape of the watershed, sufficiently so that it does not contribute appreciably to major flood peaks. Its effect is lessened still more by a measure of flood control from existing power storage developments. Below the mouth of the Passumpsic River the slope of the Connecticut River is relatively flat, most of the fall being concentrated at a few places, and the valley provides considerable channel storage, especially between Mile 340 and Mile 220. These factors tend to increase the concentration period and therefore to lessen the magnitude of maximum flood discharges.

Storm and Flood History

29. Storms.- Intense storms have occurred at frequent intervals over various parts of the New England States, and when conditions have been conducive to a high percentage of run-off disastrous floods have occurred. In Table 3 are given the maximum total rainfalls at a single station, classified by months of occurrence, for all storms, within the period from 1906 to 1936, for which the one-day maximum rainfall was three inches or more. It may be seen that the frequency of their occurrence is much greater for the period from June through November than for the period from December through May. In the latter period, however, many storms have occurred with total rainfall in the magnitude of those

classified, but with one-day maximums of less than four inches. Most of the storms shown in the tabulation occurred at times when the ground was not saturated, and, as a result, a relatively small part of the storm rainfall appeared as surface run-off, but each one represents a potential flood, and indicates the possibilities of flood occurrence within the various seasons.

Physical measurements of the rainfall during great storms within the Connecticut Basin extend back to 1869. Since then the maximum rainfalls have occurred on the following dates:

October	3 - 4, 1869
July	12 - 14, 1897
November	3 - 4, 1927
September	16 - 17, 1932
March	18 - 21, 1936

Three of these, 1869, 1927, and 1936, produced severe floods. Relatively little damage followed that of 1897, and so little of the 1932 storm appeared as runoff that no damage was sustained. Indicative of the intense storms that may occur on small areas is the one of August 8-9, 1874, at New London, Connecticut, when a total rainfall of 14.6 inches was measured. This is the maximum recorded two-day rainfall in the New England States.

30. Connecticut River floods.- Records of past floods in the Connecticut Basin extend back nearly 300 years. Prior to about 1870, however, data are meager, and, for floods in excess of 27 feet on the Hartford gage, stage hydrographs for the entire basin are available only for the 1927 and 1936 floods. In Table 4 are given the maximum flood stages of record for the Connecticut River at Hartford, Springfield, and Holyoke.

The number of floods with stages exceeding 23 feet at Hartford that occurred in each month are as follows:

January	5	May	2	September	0
February	5	June	1	October	1
March	13	July	1	November	1
April	11	August	1	December	1

It can be seen that floods have occurred in every month but September. More than half the total number of floods recorded occurred in March and April, and about half the remainder, in January and February. The comparative scarcity of floods from May through December may be attributed to both the normally low percentage of runoff and to the local rather than general character of the storms in that period. A brief description of the 1927 and 1936 floods follows.

31. The 1927 Flood.- During the month prior to the November 1927 flood, the ground was well saturated from a series of minor rainfalls considerably in excess of the normal. The rainfall from November 2 to 4 broke all previous records for continuous rain in Vermont, and also all 24-hour records. It extended with lesser intensity over the entire Connecticut River Basin. In general, the intensity on that part of the watershed west of the river was greater than for that part east of the river. The tributaries rose rapidly, and crested between the afternoon of the 3rd and the morning of the 4th. The floods were highest in the region of greatest rainfall, about 60 per cent of it appearing as runoff. On the upper Connecticut River above the mouth of the Passumpsic River the crest was characteristically delayed, passing Waterford on the morning of the 6th. Below White River Junction, where the crest occurred on the morning of the 4th, the main river crest was largely a function of the White River flood.

32. The 1936 Flood.- Although there were two consecutive rises in the Connecticut River Basin during March 1936, only the second was a flood of major proportions. On March 10 there were from 10 to 40 inches of snow on the Basin and the ground was frozen. During the 11th and 12th, 1.5 to 7 inches of rain fell and was accompanied by a rise in temperature,

which stayed around 50° F for the remainder of the month. By the 16th most of this rainfall, augmented by melting snow, had run off, causing little damage and carrying with it practically all the ice from the frozen streams in the norther part of the Basin. At the beginning of the major rise about half the snow still remained on the ground. With the flow in the Connecticut River and most of the tributaries still near their channel capacities, rain started falling again on the northern part of the Basin on the 16th, continued through the 19th, and fell again on the 21st. On the southern part of the Basin the rain fell on the 18th, 19th, and 21st. The average volume of rainfall was about 4.5 inches. It melted all the remaining snow. The tributaries crested from the afternoon of the 18th to the morning of the 20th and the main river from the morning of the 19th to the morning of the 21st. The total volume of runoff at Hartford was 7.2 inches, and the maximum discharge was 280,000 cubic feet per second. Two factors in addition to the melting snow combined to make this flood greater by 50 per cent at Hartford than the previous recorded maximum. First, the duration of the rainfall was approximately equal to the concentration period at Hartford, and, secondly, the rainfall on the southern part of the Basin started two days later than on the northern part, bringing relatively higher discharges from the lower tributaries into coincidence with the crest in the Connecticut River.

33. Tributary floods.- Damaging floods have often occurred on tributaries of the Connecticut River at times when the flood-forming conditions did not extend over a sufficient part of the Connecticut Basin to produce floods in the lower river, and conversely stages on some tributaries have not been damaging during floods on the lower river. Stage records on the tributaries do not date back more than twenty years except in a few instances. A comprehensive field investigation of historic floods prior to periods of record produced a wealth of descriptive information on tributary floods, but no definite flood stages, it being

generally the case that the 1927 and 1936 floods obliterated or destroyed previous high-water marks. This was not always caused by inundation, but in some instances by failure of the structure upon which the previous high-water mark was located. In Table 5 are shown the month and year in which each damaging tributary flood of historic record occurred. The number of floods that occurred in each month are as follows:

January	3	May	2	September	2
February	5	June	1	October	3
March	11	July	5	November	1
April	9	August	2	December	2

It can be seen that floods have occurred in every month of the year. Less than half the total number of floods recorded occurred in March and April, and the remainder were distributed rather uniformly throughout the rest of the year. The greater frequency of tributary summer and fall floods as compared to those of the lower Connecticut River may be attributed to the preponderance of intense local storms during those seasons, with conditions occasionally favoring a high percentage of runoff.

Characteristics of Past and Probable Future Floods

34. Connecticut River Floods.- Past Connecticut River floods have resulted from excessive rainfall alone, runoff from melting snow alone, and the combination of these two causes. Examples of the first type are the floods of October 1869 and November 1927; of the second type, the floods of April 1862 and April 1895; and of the third type, the flood of May 1854, which is described in the May 3, 1854 issue of the "Springfield Daily Republican", and of March 1936. Since snow cover is usually more uniform in depth over large areas than storm rainfall, it is normally expected that floods produced wholly or in part by melting snow cover will result in a greater total volume of run-off in the lower

Connecticut River than will floods of the first type. The flood run-off during spring floods occurs over a longer period of time than for the summer or fall floods because of two factors: (1) The maximum rate of melting snow is equivalent to merely a moderate rate of rainfall, and (2) maximum rates of rainfall during the winter or spring are usually much lower than during the summer or fall because of the comparative stability of atmospheric conditions during the cooler seasons. Consequently, lower peak rates of flood flow for the same volume of flood run-off may be expected during the spring than during the summer or fall. However, the total volume of flood run-off during the spring is generally so much greater than during the summer that the highest peak rates of flood flow will occur during the spring. As shown in Paragraph 30 damaging floods in the lower river occur much more frequently in March and April than in any other part of the year. By assuming the maximum possible coordination of all flood-producing factors, hypothetical floods can be constituted in any season of the year that will exceed all existing records. However, the degree of improbability of the actual occurrence of these floods may vary considerably. It is normally expected that the greatest floods in the lower river will occur in the spring, and that the summer or fall floods will usually be of lesser magnitude. The maximum flood flows that are expected to occur in the lower river are developed in Section 1 of the Appendix. They are, in general, from 10 to 20 per cent greater than the corresponding maxima for the March 1936 flood. In view of past occurrences, they are considered to form a conservative basis for design of river-front structures.

35. <u>Tributary floods.</u>- Tributary floods on small areas compared with the Connecticut River are usually caused by excessive rainfall, occasionally augmented by melting snow cover, and are very rarely caused by run-off from melting snow cover alone because the maximum rates of

rainfall that may occur at comparatively frequent intervals on small areas are much greater than the maximum possible rate of depletion of snow cover. The intense storm of November 1927 produced the maximum flood of record on many tributaries, while the flood of March 1936 exceeded all previous records on others. Those parts of the Connecticut Basin that were not subjected to the maximum local conditions during either of these floods are not necessarily lacking in flood problems, but rather were spared by the peculiarities of distribution of single storm intensities. The maximum possible floods should occur during the summer or fall period, when the probabilities of excessive rainfall are the greatest.

36. Flood frequencies.- Reference is made to Section 1 of the Appendix for a complete description of the determination of the frequency of peak flood flows in the Connecticut River Basin. Approximate general relations of peak discharge to drainage area for definite frequencies were determined for two divisions of the basin. The results of this study are tabulated below:

TABLE 2

RELATION OF PEAK DISCHARGE TO DRAINAGE AREA

Drainage Area in Square Miles	Instantaneous Peak Discharge in cubic feet per second per square mile					
	Connecticut Basin except for area east of main river and south of Ammonoosuc River.			Area east of Connecticut River and south of Ammonoosuc River.		
	5 year flood	20 year flood	100 year flood	5 year flood	20 year flood	100 year flood
30	85	149	234	44	76	122
70	71	120	188	34	58	92
100	65	109	171	30	50	80
200	54	89	140	23	38	60
700	34	57	85	14	21	33
1000	30	48	71	-	-	-
3000	18	27	40	-	-	-
7000	14	20	26	-	-	-
10000	13	17	22	-	-	-

TABLE 3

NEW ENGLAND STORMS, 1906 - 1936
MAXIMUM RAINFALL IN INCHES AT SINGLE STATIONS

Month	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23	'24	'25	'26	'27	'28	'29	'30	'31	'32	'33	'34	'35	'36	No. of Storms
Jan.																														4.1		1
Feb.																																0
Mar.									5.8																	4.9					7.8 10.8	4
Apr.																		5.3	4.1									8.8				3
May	5.7										6.9			4.6									3.2									4
June												4.8	3.2				7.2								5.0	6.8						5
July						5.5				6.4 5.1	6.4 5.3					6.0	5.1						3.2									8
Aug.			6.0							4.0							5.3 8.7		6.9		4.8		5.2	5.2								8
Sept.		5.1		7.4				4.8							5.8				5.7								8.3		6.3			7
Oct.	5.0 5.7	7.2				6.6		6.3										5.3						4.0			5.4					8
Nov.					5.1											4.6		5.3	4.9			9.4					4.6					6
Dec.															3.3																	1

TABLE 4

FLOOD STAGES OF RECORD-LOWER CONNECTICUT RIVER

Year	Date	River stage (feet) Hartford, Conn.	Springfield, Mass.	Holyoke, Mass.
1639	Mar. 18	(1)		
1642	May - June	(1)		
1683	July - August	26.0		
1692	February - March	26.2		
1767	Jan. 12	(1)	(1)	
1793	Feb. 21	(1)	(1)	
1798	Mar. 25	(1)	(1)	
1801	Mar. 20	27.5	21.2	
1807	Feb. 1	(1)	(1)	
1818	Mar. 5	(1)	(1)	
1824	Feb. 24	(1)	(1)	
1827	Mar. 30	(1)	(1)	
1838	Jan. 28	23.0		
1839	Jan. 29	24.2		
1841	Jan. 9	26.3		
1843	Mar. 29	27.2	20.7	
1852	Apr. 24	23.2	19.5	
1854	May 1	29.8	22.2	
1856	Aug. 21-22	23.3	18.9	
1859	Mar. 19-20	26.4	20.5	
1862	Apr. 20-21	28.7	22.0	
1865	Mar. 18-20	24.8	18.0	
1869	Apr. 22-23	26.7	20.5	11.2
1869	Oct. 5-6	26.3	21.0	12.7
1870	Apr. 20-21	25.3	19.0	9.5
1874	Jan. 9	23.9	17.5	8.0
1878	Dec. 11-13	24.5	18.5	9.2
1893	May 5-6	24.0	18.1	8.4
1895	Apr. 16-17	25.7	20.2	9.6
1896	Mar. 2-3	26.5	20.2	9.5
1900	Feb. 14-15	23.4	17.0	
1901	Apr. 8-9	25.8	19.7	11.4
1902	Mar. 4	25.3	19.2	10.8
1903	Mar. 24-25	23.4	17.4	10.6
1904	Apr. 30	21.4		
1905	Mar. 31 - Apr. 2	24.0	17.5	10.6
1907	Nov. 8-9	20.3	15.4	9.0
1909	Apr. 16-17	24.7	18.5	10.6
1910	Jan. 23	20.0	15.0	7.5
1912	Apr. 9-10	21.2	16.1	9.3
1913	Mar. 28-29	26.3	20.9	12.0
1914	Apr. 21-23	21.9	17.0	9.9
1915	Feb. 26-27	20.6	15.6	8.8
1916	Apr. 2-3	20.8	15.6	8.9
1920	Mar. 28-30	22.5	17.3	9.83
1922	Apr. 13-14	24.5	19.4	11.35
1923	Apr. 7-8	22.0	16.8	9.35
1923	May 1-2	20.4		8.40
1924	Apr. 7-8	20.7	14.5	7.8
1925	Mar. 30 - Apr. 1	20.5	16.0	9.47
1926	Apr. 26-27	20.8	16.03	9.14
1927	Nov. 3-6	29.0	22.45	14.75
1932	Apr. 12-15	20.5	15.3	9.90
1933	Apr. 19-21	26.0	19.95	13.18
1934	Apr. 13-15	23.1	14.2	10.79
1936	Mar. 13-21	37.3	28.3	16.8

(1) Great flood.

Note.- "Flood flows in New England", by C. H. Pierce, Journal of the Boston Society of Civil Engineers, vol. XI. pp. 327-375, 1924, supplied much of the above data.

TABLE 5. HISTORIC TRIBUTARY FLOODS

PERIOD	PASSUMPSIC	AMMONOOSUC	WELLS	WHITE	OTTAUQUECHEE	SUGAR	BLACK	ASHUELOT	WESTFIELD
Prior to 1771	Jan. 1770	Jan. 1770	Jan. 1770	Jan. 1770	Jan. 1770		Jan. 1770	Dec. 1738	
1771 to 1780		Fall 1771	Fall 1771	Fall 1771					
1781 to 1790	Oct. 1785	Oct. 1785	Oct. 1785	Oct. 1785	Oct. 1785		Oct. 1785		
1791 to 1800				1791	1791				
1801 to 1810			Feb. 1807					Mar. 1801 Feb. 1807	
1811 to 1820			1812 Mar. 1818	July 1811	July 1811		Mar. 1818	July 1813 Mar. 1818	
1821 to 1830	Mar. 1826 Sept. 1828 July 1830	Mar. 1826 Aug. 1826 Sept. 1828 July 1830	Feb. 1824 Sept. 1828 July 1830	Feb. 1824 Mar. 1826 Sept. 1828 July 1830	Feb. 1824 Mar. 1826 Sept. 1828 July 1830	Feb. 1824	Feb. 1824 Mar. 1826 Sept. 1828 July 1830	Feb. 1824 Sept. 1828	
1831 to 1840				Mar. 1839	Jan. 1839 Mar. 1839	Feb. 1839			
1841 to 1850	Jan. 1841	Jan. 1841	Jan. 1841 Apr. 1850	Jan. 1841 July 1850	Jan. 1841 July 1850	Jan. 1841 Apr. 1843	Jan. 1841	Jan. 1841	

TABLE 5. HISTORIC TRIBUTARY FLOODS (CONT'D)

PERIOD	PASSUMPSIC	AMMONOOSUC	WELLS	WHITE	OTTAU-QUECHEE	SUGAR	BLACK	ASHUELOT	WESTFIELD
1851 to 1860	May 1854 Mar. 1859			May 1854	May 1854 Mar. 1859	Mar. 1859		May 1854	May 1854
1861 to 1870	Apr. 1862 Apr. 1866 Apr. 1869 Oct. 1869	Apr. 1862 Apr. 1866 Apr. 1869 Oct. 1869	Apr. 1862 Apr. 1866 Apr. 1869 Oct. 1869	Apr. 1862 Apr. 1866 Feb. 1867 Oct. 1869	Apr. 1862 Apr. 1866 Apr. 1869 Oct. 1869	Apr. 1869 Oct. 1869 Apr. 1870	Apr. 1862 Summer 1869 Oct. 1869	Apr. 1862 Oct. 1869	Apr. 1862 Oct. 1869
1871 to 1880	Dec. 1878		Spring 1876 Dec. 1878						Dec. 1878
1881 to 1890							July 1883 June 1884	Sept. 1882	
1891 to 1900	Apr. 1895 Mar. 1896 May 1896	Apr. 1895 Mar. 1896	Apr. 1895 Mar. 1896	Apr. 1895 Mar. 1896	Apr. 1895 Mar. 1896		Apr. 1895 Mar. 1896	Apr. 1895 Mar. 1896 Feb. 1900	Apr. 1895 Mar. 1896
1901 to 1910									
1911 to 1920	Mar. 1913	Mar. 1913	Mar. 1913	Mar. 1913	Mar. 1913	Mar. 1913		Mar. 1913	
1921 to 1930	Nov. 1927	Nov. 1927	Nov. 1927	Apr. 1922 Mar. 1925 Nov. 1927	Nov. 1927	Nov. 1927	Nov. 1927	Nov. 1927	Nov. 1927
1931 to 1936	Mar. 1936	Mar. 1936	Mar. 1936	Mar. 1936	Mar. 1936	Mar. 1936	Mar. 1936	Mar. 1936	Mar. 1936

FLOOD LOSSES

37. General.- The Connecticut River Valley suffers frequently and severely from floods. Realization of the extent of the losses has become acute because of the great floods of 1927 and 1936. The losses from these two floods, particularly from that of 1936, afford data for estimating the benefits to be derived from a plan of flood control.

38. Direct and indirect losses defined.- Flood losses are divided broadly into direct losses, and indirect losses. Direct losses are generally the results of physical damage to property, and may be measured by the cost of repair, or replacement in kind, including cost of clean-up, and, largely in highway and railway damages, where they could not readily be eliminated, include costs of betterments which resulted from repair or replacement of damaged structures. Indirect losses are the results which are not localized, of the direct damages, and are primarily the value of the service or use lost, or made necessary, by the occurrence of the flood.

39. Classification of direct losses.- Direct losses have been classified as follows:

Urban losses include losses of homes and places of habitation located in towns and cities, losses of sanitary and water supply facilities, damages to educational and religious institutions, parks and playgrounds, and miscellaneous municipal losses.

Rural losses include losses similar to those indicated for urban areas but not located in towns and cities, and in addition, land, crop and livestock losses.

Industrial losses cover all manufacturing, light and power developments, telephone and telegraph facilities, fuel and petroleum product losses.

Highway losses include damage to all roads and pavements with appurtenant drainage structures, bridges and viaducts, and to highway transportation maintenance and operating equipment.

Railway losses include track, right of way, bridge and culvert losses, damages to loading, storage and terminal facilities, as well as to stocks and supplies and train equipment.

40. Losses of 1927.- The following tables summarize the 1927 direct flood losses:

TABLE 6

SUMMARY OF 1927 DIRECT FLOOD LOSSES - BY STATES

Losses are in Thousands of Dollars

State	Urban	Rural	Industrial	Highway	Railroad	Total	Per Cent
Vermont	1,780	169	1,181	4,960	2,891	10,981	70.7
New Hampshire	115	76	110	1,336	130	1,767	11.4
Massachusetts	505	275	507	295	575	2,157	13.9
Connecticut	275	145	126	0	75	621	4.0
Totals	2,675	665	1,924	6,591	3,671	15,526	100.0
Per Cent	17.2	4.3	12.4	42.5	23.6	100.0	

(Table on following page)

TABLE 7

DIRECT LOSSES - CONNECTICUT RIVER WATERSHED

SUMMARY OF 1927 LOSSES BY RIVER BASINS

River Basin	State	Damages (in thousands of dollars)					
		Urban	Rural	Indus-trial	Rail-road	High-way	Total
Connecticut *	Various	846	565	1,155	887	554	4,007
Israel	New Hampshire		2	10	5	45	62
Passumpsic	Vermont	563	50	185	475	1,311	2,584
Ammonoosuc	New Hampshire	35	6		110	829	980
Stevens	Vermont			1		22	23
Wells	Vermont	98	3	60	186	289	636
Waits	Vermont					56	56
Ompompanoosuc	Vermont		1	4		88	93
White **	Vermont	751		250	1,195	1,985	4,181
Ottauquechee	Vermont	16	10	21	20	465	532
Black	Vermont	251	20	120	130	195	716
Williams	Vermont					63	63
Saxtons	Vermont					59	59
West	Vermont		8	10	113	370	501
Westfield ***	Massachusetts	100		82	550	260	992
Farmington	Connecticut	15		26			41
Total		2,675	665	1,924	3,671	6,591	15,526
Percent of total		17.2	4.3	12.4	23.6	42.5	100

* Exclusive of tributaries listed in table. There were 6 lives lost.
** There were 9 lives lost in White Basin.
*** There were 6 lives lost in Westfield Basin.

41. <u>Losses of 1936.</u>- The losses from the 1936 flood were extremely severe in the lower reaches in spite of the lessons learned from the 1927 flood and steps taken by many industries and individuals to protect themselves against damages from a flood by moving vulnerable equipment to higher levels and moving stock or household goods to higher places when the danger of another flood became apparent. In the more important industrial towns extensive areas were inundated and water often reached over the second floor of buildings. Almost 10,000 homes were flooded. Approximately 64,000 acres were inundated of which more than 46,000 acres were in Connecticut and Massachusetts. Of these 64,000 acres, about 34,500 were agricultural land, of which over 4,600 acres were made unusable by erosion or heavy deposits, and over 6,000 acres damaged to some extent by lighter deposits. Only in a few rare cases have those light deposits proved beneficial to agriculture. Farmland in some localities not only received harmful deposits of natural materials but also suffered from deposits of chemicals, oils and other materials, for example, paper pulp, originating in inundated industrial areas. These losses are shown in detail in Section 2 of the Appendix and are summarized in the following tables:

TABLE 8

SUMMARY OF 1936 DIRECT FLOOD LOSSES - BY STATES

1936 Direct Flood Losses in Thousands of Dollars Estimate

State	Urban	Rural	Industrial	Highway	Railroad	Total	Per Cent
Vermont	101	183	337	691	453	1,765	5.1
New Hampshire	56	163	538	1,375	210	2,342	6.8
Massachusetts	4,948	955	7,366	4,774	957	19,000	55.1
Connecticut	3,540	376	6,469	881	127	11,393	33.0
Totals	8,645	1,677	14,710	7,721	1,747	34,500	100.0
Per Cent	25.0	4.9	42.6	22.4	5.1	100.0	

TABLE 9

DIRECT LOSSES - CONNECTICUT RIVER WATERSHED

SUMMARY OF 1936 LOSSES BY RIVER BASINS
(Not limited to losses below reservoirs)

River Basin		State	Damages (1936) (In thousands of dollars) Urban	Rural	Indus-trial	Railroad	Highway	Total
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)
Connecticut	(1)	Conn. Mass. N.H. & Vt.	7,916	1,508	12,066	1,129	4,914	27,533
Israel	*	N.H.				1	23	24
Passumpsic		Vt.	12	6	38	10	6	72
Ammonoosuc		N.H.	6	10	20	4	95	135
Stevens		Vt.					3	3
Wells	(2)	Vt.	2		3			5
Waits		Vt.					4	4
Ompompanoosuc		Vt.					1	1
White	(3)	Vt.		3	2	24	13	42
Ottauquechee		Vt.	1		9		5	15
Black		Vt.	9	1	12	5	47	74
Williams	*	Vt.					10	10
Saxtons		Vt.					15	15
West	(4)	Vt.		3	9		127	139
Westfield		Mass.	85	32	128	43	96	384
Farmington		Conn. Mass.	64	8	154	10	99	335
Total			8,095	1,571	12,441	1,226	5,458	28,791
Per Cent of Total			28.1	5.4	43.2	4.3	19.0	100.0
Other Rivers								
Mascoma	*	N.H.	1		18	40	36	95
Sugar		N.H.	2	1	23	9	108	143
Ashuelot		N.H.	31	15	355	9	126	536
Cold River	*	N.H.		1			35	36
Millers	(5)	Mass. N.H.	340	20	1,239	279	719	2,597
Deerfield	*	Vt. Mass.	4	8	19	92	317	440
Chicopee		Mass.	17	19	489	45	849	1,419
Misc., Other Streams	*	Various	155	42	126	47	73	443
Total, Other Rivers			550	106	2,269	521	2,263	5,709
GRAND TOTAL			8,645	1,677	14,710	1,747	7,721	34,500
Per cent of Total			25.0	4.9	42.6	5.1	22.4	100.0

* No detailed investigation for 1936 stage-loss relationship.
(1) Exclusive of tributaries listed in table. There were 6 lives lost.
(2) There was one life lost in Wells River Basin.
(3) There were two lives lost in White River Basin.
(4) There was one life lost in West River Basin.
(5) There was one life lost in Millers River Basin.

42. Comparison of 1927 and 1936 losses.- The flood of 1936 was much more severe than that of 1927, and the distribution of losses was much different. Of the total damage of the 1927 flood, 82 per cent occurred in Vermont and New Hampshire, whereas 88 per cent of the damage of the 1936 flood occurred in the thickly populated and highly industrial states of Massachusetts and Connecticut. In 1927 the losses to highways and railroads accounted for about 66 per cent of the total, whereas in 1936 the highway and railroad losses amounted to only about 27 per cent of the total, although of about the same amount as those of 1927. This is accounted for largely by the fact that after the 1927 flood many of the highways had been relocated at higher levels, bridges were higher, stronger, and provided greater waterway, and construction generally was of more substantial types than had existed prior to the flood. The fact that several railroad lines, industries and urban structures which suffered extensive losses in 1927 were no longer in existence at the time of the 1936 flood must also be taken into account.

43. Distribution of recurring losses.- To provide a basis for estimating the effect of proposed reservoirs on flood losses the entire watershed, below the reservoir sites studied, was divided into 49 damage zones which are described in greater detail in Section 2 of the Appendix, and the 1936 losses were allocated to their respective damage zones. Where available in sufficient detail to permit allocation to damage zones, and where they indicated the upper limit of known damages, 1927 data were also used. Storm damage on minor tributaries or above proposed reservoir locations, and losses which were clearly non-recurring, were eliminated. Conversely, some losses were increased, as for instance, when it was known that a temporarily unused factory building was damaged, which at the present time is reoccupied, and, therefore, is subject to additional stock losses, if a flood of a magnitude

comparable to that of 1936 should occur. In this manner the "recurring" losses that can be reduced or eliminated by the construction of flood-control works were determined for each damage zone and type of loss, based upon the 1936 flood experience. Table 10 summarizes the recurring losses by damage zones based upon the 1936 flood.

(Table on following page)

TABLE 10

DIRECT FLOOD LOSSES - CONNECTICUT RIVER WATERSHED
Summary of Recurring Losses below Considered Reservoir Sites Based upon 1936 Flood Losses

RIVER (1)	ZONE (2)		DIRECT FLOOD LOSS URBAN (3)	RURAL (4)	INDUSTRIAL (5)	HIGHWAY (6)	RAILROAD (7)	TOTAL (8)
Connecticut Conn.	10	(1)	3,372,400	313,700	6,111,600	770,500	108,800	10,677,000
"	9	(1)	47,500	36,200	199,500	33,300	7,900	324,400
Mass.	8	(1)	3,473,200	104,900	3,870,000	538,600	171,100	8,157,800
"	7	(1)	931,800	484,900	1,701,700	2,128,400	199,100	5,445,900
Mass., Vt., N. H.	6	(1)		269,900	5,900	150,100	191,400	617,300
Vt., N. H.	5	(1)	9,600	140,700	192,000	364,500	298,000	1,004,800
" "	4	(1)	1,500	64,900	15,400	182,800	43,600	308,200
" "	3	(1)	47,900	29,300	87,600	111,000	34,400	310,200
" "	2	(1)	15,300	22,000	8,700	563,800	38,000	647,800
" "	1	(1)	13,300	28,200	12,200	24,400	26,500	104,600
Total for Connecticut River			$7,912,500	$1,494,700	$12,204,600	$4,867,400	$1,118,800	$27,598,000
Tributary Streams								
Passumpsic & Moose, Vt.	1-f	(1)	6,700	3,300	7,800	3,500	800	22,100
" " " "	1-d	(1)	-	-	-	2,500	2,000	4,500
" " " "	1-e	(1)	5,700	2,800	25,000	-	7,000	40,500
Stevens, Vt.	2	(1)	-	-	-	3,000	-	3,000
Wells, Vt.	3	(1)	1,600	-	3,200	-	-	4,800
Ammonoosuc, N. H.	4-a	(1)	4,000	4,100	10,500	9,700	-	28,900
" "	4-b	(1)	1,600	6,000	9,200	14,700	2,900	34,400
Waits, Vt.	5	(1)	200	-	-	-	-	200
White, Vt.	7-a	(1)	-	-	-	8,000	-	8,000
" "	7-e	(1)	-	-	-	-	-	0
" "	7-b	(1)	100	200	-	4,000	-	4,300
" "	7-c	(1)	300	2,100	1,600	1,300	24,000	29,300
Mascoma, N. H.	8-a	*	500	-	2,200	3,700	11,800	18,200
" "	8-b	*	-	-	14,000	-	28,500	42,500
Ottauquechee, Vt.	9		700	-	8,200	3,200	-	12,100
Sugar, N. H.	10-a		-	1,400	2,000	26,400	8,000	37,800
" "	10-b	(1)	1,300	0	20,500	29,600	0	51,400
Black, Vt.	11-a		2,500	300	9,500	9,300	5,000	26,600
" "	11-b	(1)	6,500	600	2,800	30,600	-	40,500
Saxtons, Vt.	12		-	-	-	3,300	-	3,300
West, Vt.	13	(1)	-	2,600	4,000	25,000	-	31,600
Ashuelot, N. H.	14-g	(1)	26,800	6,500	191,200	21,000	1,100	246,600
" "	14-f	(1)	2,900	7,900	149,800	25,000	8,000	193,600
Millers, Mass.	15-c	(1)	188,200	-	286,000	166,500	9,400	650,100
" "	15-e	(1)	2,200	3,200	289,500	142,000	84,500	521,400
" "	15-f	(1)	-	-	-	27,000	-	27,000
" "	15-g	(1)	148,600	12,300	610,500	168,900	132,900	1,073,200
" "	15-h	(1)	-	-	50,000	36,600	51,600	138,200
Deerfield, Vt.	16-a	*	-	1,500	-	66,800	64,400	132,700
" Mass.	16-b	*	3,500	6,400	19,100	216,300	27,300	272,600
Swift & Chicopee, Mass.	17-a & b		0	8,700	61,000	39,100	2,400	111,200
Westfield, Mass.	18	(1)	78,400	17,000	112,100	64,800	41,000	313,300
Farmington, Mass.	19-a		0	900	200	500	0	1,600
" Conn.	19-b		12,000	500	83,400	22,300	0	118,200
" "	19-c		2,600	5,200	9,900	5,300	10,200	33,200
Quaboag, Mass.	21		3,400	3,700	19,900	50,600	18,900	96,500
Ware, Mass.	22		10,000	7,000	156,600	90,100	22,000	285,700
Total for Tributary Streams			$510,900	$104,200	$2,159,700	$1,320,600	$563,700	$4,659,100
GRAND TOTAL			$8,423,400	$1,598,900	$14,364,300	$6,188,000	$1,682,500	$32,257,100
20-Reservoir Plan (1)								
Connecticut River Zone Total			7,912,500	1,494,700	12,204,600	4,867,400	1,118,800	27,598,000
Tributary Streams Zone Total			475,700	68,600	1,773,700	783,700	365,200	3,466,900
Total			8,388,200	1,563,300	13,978,300	5,651,100	1,484,000	31,064,900
Zones outside 20-Reservoir Plan			35,200	35,600	386,000	536,900	198,500	1,192,200

Note: * Indicates 1936 Flood Losses; no detailed investigation.
(1) Indicates Zones Affected under the 20-Reservoir Plan.

44. Stage-loss relationship.- The relationship between flood loss and flood stage was determined primarily from the 1936 flood losses, the details of which provide the only basis sufficiently complete for such a determination. Losses, which could be classed as controlling losses within each damage zone, because of their magnitude, or their analogy to other losses of a large group, were investigated and the effects of increases in flood stages ascertained, from the stage at which damage begins to the estimated maximum flood crest. From these data diagrams were prepared for each damage zone showing expected direct losses for floods of various magnitudes, which in combination with hydrologic data form the basis of the relations of flood losses to frequency described in Section 2 of the Appendix.

45. Average annual direct flood losses.- Average annual direct flood losses were determined for each damage zone with the use of the relation of stage to direct flood loss for the zone, and with the probable frequency of recurrence of flood stages determined from an analysis of the hydrological data of record in the watershed. Reference is made to Section 2 of the Appendix for a detailed description of this determination. Verification of the accuracy of the method was obtained by computing the average annual direct flood loss for those damage zones with records of flood stages for a period of one hundred years or more by entering the (stage-flood loss) relation with each maximum flood stage during that period, summating the individual flood losses for these stages, and dividing the total loss during that period by the number of years within the period. For damage zones without extended periods of record of flood stages, the frequency method made possible an evaluation of average annual flood loss that could not otherwise have been obtained.

46. Losses related to direct losses.- The effects of disruption of production and transportation and the interference with the normal life of whole communities result in indirect losses which are severe in

the vicinity of flooded districts and are felt to some extent throughout the nation. Many of them cannot be stated in money value, as for instance the loss of lives, important records and heirlooms, or the anguish of people who have lost the fruits of many years of toil and privation. It has not been possible to completely evaluate indirect losses because of the reluctance shown by many interests to estimate these losses and the difficulty experienced by others in estimating the value of certain portions of the indirect losses. Evaluation if possible for only the group of indirect losses described in paragraph 47, which are closely associated with direct losses. Even these can be only partially evaluated. No estimates are available measuring the extent of the losses enumerated in paragraph 49, but they cause a pronounced depreciation of normal property values, which may be estimated.

47. <u>Description of indirect related losses</u>.- These losses are obvious and closely associated to directly affected territories, and are proportional to direct losses. They are described in more detail in Section 2 of the Appendix. The more important types are the following:

(a) Loss of normal business to establishments directly damaged, their suppliers and customers.

(b) Loss of wages to employees in shut-down industries, and in industries forced to curtail their production because of these shut-downs.

(c) Loss of good-will and disruption of markets.

(d) Loss of income by reason of curtailed dividend payments, loss of rent, or expenditures for rental because facilities normally used have been rendered unserviceable.

(e) Losses because of highway and railroad detouring; not only loss of business to transportation companies, but also losses because of non-delivery of goods; extra cost to motor travel because of longer routes over inferior roads, extra cost of maintenance or reconstruction of roads because of use of inferior highways for traffic they cannot bear.

(f) Interruption of power, light and heat service.

(g) Expenditures to alleviate distress conditions, prevention of sickness or epidemics, sanitation, policing and ferrying.

(h) Extra cost of raw materials and power.

(i) Cost of capital needed to replace direct losses.

48. Estimate of related losses.- To determine the value of the indirect losses, approximately 1,215 individual losses in the industrial and urban classifications were investigated, all available data were obtained from railways and highway sources, and special inspections were made of the rural areas. Such portions of the indirect losses as are susceptible to evaluation support the following ratios of indirect to direct losses:

Urban	114%
Industrial	114%
Highway	50%
Railroad	70%
Rural	10%

Upon the basis of these ratios it is estimated that the indirect losses below the reservoir sites considered amount to $30,410,000, or 94.5 per cent of the total direct recurring losses of $32,257,000 below these sites. Because it is necessarily based upon a partial evaluation of indirect losses this ratio of indirect to direct losses is considered conservative. The detailed data regarding indirect losses are given in Section 2 of the Appendix.

49. Intangible indirect losses.- The expectation of recurrent flooding of an inadequately protected community or area results in effects, the values of which cannot readily be expressed in terms of money, but which, nevertheless are real losses. They are not taken account of in the computations of economic justification, but merit consideration in a broad estimate of the worth of proposed protection. Among the considerations that are the basis for this class of losses are the following:

(a) Possibility of loss of life; the 1936 flood cost at least 11 lives by drowning and one by suicide.

(b) Mental distress caused by losses and apprehension of future damages.

(c) Stopping of industrial expansion or additional development.

(d) Lack of credit for repair or construction in areas subjected to flood.

(e) Exodus of industries and people from the flooded area.

(f) Effect upon social security of inhabitants.

50. Depreciation of property values.- In addition to the direct and indirect losses discussed in the preceding paragraphs, and not reflected in the computations of them, the March 1936 flood caused a decided depreciation of property values throughout the flooded areas owing primarily to the apprehension of a recurrence of similar floods. This computation of depreciation does not include the capitalized value of future average annual direct and indirect flood losses described in paragraphs 45 to 48 inclusive of the report. While there is a tendency, in the absence of disastrous floods over a period of years, for a gradual recovery of these depreciated values, the successful control of otherwise damaging floods will prevent the recurrence

of this depreciation and its consequent loss, and thus will hold property values at normal levels or those levels existent after a period free from devastating floods.

51. Information on depreciation.- As 80 per cent of the assessed valuations of flooded areas is within the heavily populated industrial centers, investigations for information on depreciation of property values were limited to these localities. Information was obtained by interview and correspondence with bankers, real estate men, assessors, and various other reliable local sources. Statements made in response to questionnaires are summarized as follows:

(a) Substantial losses are sustained because of inability to rent or sell property in flooded areas; practically no bona fide sales are recorded.

(b) Mortgaged property reverts back to mortgage holders at a greater than normal rate.

(c) Credit is restricted for the improvement of properties in flooded areas; the Federal Housing Administration makes no loans on such property.

(d) Forced sales had to be made at a fraction of normal, or pre-flood, values.

The following additional points have been disclosed in interviews: tax collections are retarded; a more than normal proportion of properties are now subject to tax liens; industrial expansions in flooded areas have been deferred until adequate flood protection will be provided; and there is much concern that one more flood of the order of that of 1936 will bring about cessation of many industrial activities and abandonment of plants and houses.

52. <u>Estimated depreciation based on assessed valuation.</u>- The assessed values of homes in Massachusetts and Connecticut agree substantially with independent appraisals made by the Home Owner's Loan Corporation. In view of this, the most recent available assessment figures, generally those of 1935, were used as the normal or pre-flood property values. The estimates of depreciation of property values, which varied from 10 per cent to 75 per cent of normal values, were based on opinions of local interests. The estimated assessed valuation of property in flooded areas which will be protected by the proposed Comprehensive Plan, (See Summary of Plan, Paragraph 137), is $330,816,000 and the estimated depreciation of property values is $74,857,000. Tables 11 and 12 show, with other pertinent data, the breakdown of these figures by damage zones and by states. If complete flood protection were provided, losses because of depreciation of property values would be eliminated within a short time, probably before the completion of the construction of the works. Without flood control these values would partially recover, provided another disastrous flood did not occur for a number of years. It is estimated that approximately 80 per cent of the loss can be eliminated in the Connecticut Valley by complete protection from future disastrous floods. Upon the assumption that real estate should bring a minimum return of 6 per cent, the estimated annual loss then would be not less than 6 per cent of 80 per cent of $74,857,000 or over $3,593,000, which can be eliminated by complete protection from future disastrous floods.

(Table on following page)

TABLE 11
Estimate of Depreciation of Property Values in Flooded Towns, Flood of 1936. Connecticut River Watershed. Twenty-Reservoir Plan.

River	Zone	Total Population 1930 Census	Total Pre-Flood Assessed Valuation	Est. Value of Property in Flooded Areas	Est. Depreciation of Property Values
(1)	(2)	(3)	(4)	(5)	(6)
Connecticut	10	250,264	$ 484,103,339	$ 156,441,150	$ 38,819,000
	9	30,638	44,648,075	5,830,000	453,000
	8	216,946	397,281,774	104,381,200	25,970,000
	7	132,630	191,200,164	25,456,900	5,341,000
	6	3,505	3,891,865	717,000	81,000
	5	16,780	19,324,815	4,794,000	540,000
	4	6,750	11,662,440	1,420,000	181,000
	3	10,881	10,689,946	3,227,000	250,000
	2	8,728	11,185,628	570,000	53,000
	1	7,702	15,711,821	452,000	54,000
Total for Connecticut River		684,824	$1,189,649,886	$302,289,250	$71,722,000
Tributary Streams					
Passumpsic, Vt.	1f	7,471	5,711,133	1,230,000	126,000
& Moose, Vt.	1d	2,234	2,098,673	245,000	17,000
"	1e	5,094	4,825,676	400,000	22,000
Stevens, Vt.	2	260	266,000	20,000	1,000
Wells, Vt.	3	1,869	1,459,648	65,000	6,500
Ammonoosuc, N.H.	4a	5,880	8,652,446	260,000	12,000
"	4b	2,274	3,152,412	200,000	10,000
Waits, Vt.	5	370	331,000	50,000	2,500
White, Vt.	7a	2,110	1,359,788	550,000	24,000
"	7e	1,957	2,401,640	240,000	30,000
"	7b	1,491	848,281	100,000	10,000
"	7c	2,747	2,793,288	420,000	21,000
Sugar, N.H.	10b	9,877	11,193,480	2,160,000	90,000
Black, Vt.	11b	4,443	8,494,052	200,000	20,000
West, Vt.	13	1,832	1,553,850	230,000	28,000
Ashuelot, N.H.	14g	17,593	21,152,052	5,350,000	535,000
"	14f	1,857	3,140,375	600,000	60,000
Millers, Mass.	15c	6,202	5,741,929	2,000,000	200,000
"	15e	6,094	6,760,183	4,200,000	420,000
"	15f	1,050	1,180,695	300,000	0
"	15g	10,628	12,119,899	7,300,000	730,000
"	15h	630	1,123,849	500,000	170,000
Westfield, Mass.	18	23,095	26,627,934	1,907,000	600,000
Total for Tributaries		117,058	$132,990,286	$28,527,000	$3,135,000
Total (20-Reservoir Plan)		801,882	$1,322,640,172	$330,816,250	$74,857,000

TABLE 12

Estimate of Depreciation of Property Values in Flooded Towns,
Flood of 1936, Connecticut River Watershed
(Twenty Reservoir Plan)

State	Total Population 1930 Census	Total Preflood Assessed Valuation	Est. Value of Property in Flooded Areas	Est. Depreciation of Property Values
(1)	(2)	(3)	(4)	(5)
Vermont	63,769	$ 69,000,000	$ 12,321,000	$ 1,125,000
New Hampshire	57,065	80,000,000	10,517,000	953,000
Massachusetts	400,146	645,000,000	146,707,000	33,507,000
Connecticut	280,902	529,000,000	161,271,000	39,272,000
TOTAL	801,882	$1,323,000,000	$330,816,000	$74,857,000

53. Relationship of flood losses to flood protection benefits.- A substantial portion of the flood losses may be eliminated by the construction of flood-control works. The measure of the benefits to be derived from protective works is the degree of prevention of losses afforded by them. The value of such benefits forms the basis for their economic justification. Benefits for which values have been calculated are the following:

(a) Direct recurring losses below proposed reservoir sites, the benefit being the losses determined from stage or discharge reductions, and stage-loss or discharge-loss relations.

(b) Indirect losses, which have been taken as 94.5% of direct losses.

(c) Depreciation of property values.

54. Method of allocating benefits - to reservoirs and dikes.- Essential requirements of flood-control works are to reduce the annual average direct and indirect losses in the entire watershed, and to obtain

a dependable reduction of losses during all floods, to the extent practicable. Reservoirs, properly distributed, fulfill both requirements in the valleys below them. Dikes eliminate damage in the limited areas behind them. The allocation of benefits to reservoirs and dikes is based on their relative economic priorities in producing each type of benefit. Detailed economic studies showed that the annual cost of dikes to protect urban areas in the lower Connecticut River is higher in comparison with the annual benefits from reduction of direct and indirect losses than the corresponding ratio for reservoirs alone. Benefits of this type are therefore allocated first to reservoirs, and the amount given to dikes is the additional annual benefit that will result from the elimination, by this supplementary protection, of losses caused by the floods against which the reservoirs will not provide complete protection. The comparative dependability of reservoirs during the greatest floods justifies this method of allocating annual benefits from the reduction of direct and indirect losses. Complete protection of diked areas by a combination of reservoirs and dikes results in a large benefit by restoring to property values the depreciation caused by a disastrous flood and sustained by the flood menace. This is allocated entirely to dikes on the grounds that very little of it will materialize unless they are added. The benefit from restoration of property values in the valley outside the diked areas is relatively small and is, of course, allocated entirely to reservoirs.

55. Summary.- The direct flood losses resulting from the 1927 flood were $15,526,000, and from the 1936 flood were $34,500,000. The related indirect losses based on the study of the 1936 losses are estimated at 94.5 per cent of the direct losses. Property having an assessed value of approximately $330,816,000 was submerged by the 1936 flood, and it is estimated that these property values suffered a depreciation of $74,857,000.

The elimination of non-recurring direct losses, the determination of the stage-loss relationships, and their use in connection with the probable frequency of recurrence of flood stages, establish the basis for determining the average annual direct benefits. The indirect benefits are then estimated at 94.5 per cent of the direct benefits. The average annual benefit through restoration of depreciation is estimated at a return of 6 per cent on the depreciation which will be avoided by protection. These benefits are allocated to reservoirs and dikes as described in paragraph 54, and as further described in paragraph 82 for the reservoirs, and paragraph 96 for the dikes. The total annual benefits to accrue from the construction of the Comprehensive Plan, exclusive of benefits that are not susceptible of a money evaluation, amount to $5,268,000 as further stated in paragraph 137.

(Report continued on following page)

IMPROVEMENT DESIRED

56. Protection.- The improvement desired is that which will provide protection against repeated inundations of homes, lands, industries, and utilities, with their attendant loss of life, direct damage, disruption of normal activities, loss of employment, additional expense, depression in values, and threat to communal stability and social security. As the losses over a long period of time have been fairly well spread throughout the valley, somewhat in proportion to industrial and social development, it is desired that the improvement provide protection to all parts of the valley to the extent practicable and justified.

57. Measures advocated.- The larger, thickly populated, highly developed, and highly industrialized centers have looked first to dikes and desire the complete protection afforded by them. The enlargement of the channel of the main river has been advocated at several localities where narrows or other obstructions exist. The construction of a system of reservoirs to detain flood waters in the upper reaches of the valley and release them in such a manner as to substantially reduce flood flows and stages has also been advocated and is generally agreed to be of greatest general benefit to the valley as a whole, and the proper basis for a comprehensive plan of flood control.

58. Conservation.- In the development of a system of reservoirs it is desired to preserve or develop the potentialities of the sites for the conservation of water for power, recreation, or other purposes. In this connection it is recognized that the development of those sites where conservation is desired and justified, can readily be accomplished for flood control and conservation if local interests will contribute the additional cost over that for flood control only.

SURVEYS

59. Surveys - Surface.- In the investigations for the 308 Report, published as House Document 412, 74th Congress, 2d Session, surveys were made of all of the principal tributaries on which it was thought possible that reservoir sites could be developed, and nearly 300 potential dam sites were considered. Preliminary estimates and field reconnaissance reduced the number of sites that showed promise of being suitable for flood control to about 60, and those that merited study for a comprehensive plan of flood control, to the list hereinafter described. Surveys were made on 40 dam sites and a number of prospective dike locations. The reservoir areas were cross-sectioned wherever necessary to supplement existing reliable topographic data on these areas. Aerial surveys of the reservoir areas were made by the Air Corps, United States Army, the photographs enlarged, and used in the field to greatly facilitate the instrumental work.

60. Subsurface investigation.- Geological investigations have been made at 33 of the sites by borings to rock, core borings, test pits, and auger borings, to determine the character of the overburden, and the location and character of the rock. A total of 225 core borings were made by contract, and by Government-owned rigs and hired labor. About 970 earth samples and many rock cores were obtained by these borings. Nearly 2,900 test pits, and 400 auger borings were dug by hired labor in the overburden forming abutments, foundations, and potential borrow areas, and about 2,900 earth samples were obtained from them. The samples of earth and rock have been stored at the District Soils laboratory, which has analyzed representative samples to determine their suitability, and as a guide for the preliminary designs which form the basis of the estimates given herein. Borings were made on proposed dike locations to determine the character of subsurface materials.

CONSERVATION FOR POWER

61. Existing hydroelectric developments.- There are sixty-three hydroelectric plants in the Connecticut River Basin producing power for sale. They have an aggregate installed capacity of about 440,000 kilowatts, or about 72 per cent of the total capacity of the "zone" comprising the five New England States, exclusive of Maine, which interchanges but little power with other States in New England. These hydroelectric plants generated in the year 1932 about one and one-half billion kilowatt-hours of electrical energy. The larger part of the output of these plants is controlled by the New England Power Association, and is operated as a unified system with the larger steam plants of this Association and of the Edison Electric Illuminating Company of Boston. Of the above installed capacity, about 280,000 kilowatts are located in the Cabot Station at Turners Falls and four power stations of the New England Power Association on the Connecticut River above Turners Falls. Eight power stations, having a combined capacity of about 90,000 kilowatts, are located on the Deerfield River. The greater part of the other smaller electric plants and many industrial plants operated by water power are located on uncontrolled tributaries of the Connecticut River. The total installed capacity of all hydroelectric plants in the zone is approximately 616,000 kilowatts, and the output of electric power from these plants during the year 1936 was approximately 1,900 million kilowatt-hours.

62. Production of electric power in "zone".- The production of electric power in the "zone" shows a very consistent growth from approximately 3,300 million kilowatt-hours in the year 1922 to 5,300 million in 1928 representing an average rate of increase of about 320 million

kilowatt-hours per year. The maximum yearly output of electric power before 1930 in the zone was reached in the year 1929 when the production was about 5,889 million kilowatt-hours. During the three years following 1929 the output dropped to 4,954 million kilowatt-hours for the year 1932. Since 1932 the output has increased to about 6,513 million kilowatt-hours for the year 1936. The present weekly production of electric power in New England is averaging 10 to 15 per cent more than was produced in the corresponding period of the year 1936. With a continued increase in the demands for electric power, and the combined capacity of the hydro and steam plants less than in 1932, it appears only a question of time before additional generating capacity will become necessary.

63. Existing storage reservoirs.- Existing reservoirs and those under construction, or proposed, within the basin are:

TABLE 13

EXISTING STORAGE RESERVOIRS

Reservoir	River	Drainage Area Sq. Mi.	Storage Acre-feet
Upper Connecticut Lakes	Connecticut	82	88,300
Pittsburg*	"	84	96,500
Grafton Pond, Goose Pond, Crystal & Mascoma Lakes	Mascoma	153	28,800
Sunapee Lake	Sugar	45	19,800
Somerset & Harriman	Deerfield	184	178,000
Quabbin**	Swift and Ware (Chicopee)	187	1,274,000
Cobble Mountain	Westfield	45	70,000
Otis, Compensation and Nepaug	Farmington	112	56,600
TOTAL		892	1,812,000

* Early construction by combined State and private agencies anticipated.
** Under construction.

The existing power developments have pondage in various amounts, but their effect upon flood flows cannot be established. The reservoirs on the Mascoma and the Sugar Rivers are natural lakes of relatively small capacity, and are of but little value for regulating or increasing the low-water flow below the reservoirs. The Swift, Westfield, and Farmington River reservoirs are primarily for water supply, and are of no material benefit to any water powers. The Upper Connecticut Lakes reservoirs were constructed and are operated by private interests for the benefit of the power plants on the Connecticut River. During the dry seasons of the year the low-water flow is increased about 600 cubic feet per second. The Harriman and Somerset reservoirs, on the Deerfield River, which were constructed and are operated by the New England Power Association, increase the low-water flows of the Deerfield and of the Connecticut Rivers below Greenfield by varying amounts up to 600 cubic feet per second.

64. Prospective future power plants.- The most economical and easily improved head for water power in the basin has been developed. Consideration has been given by the New England Power Association to the development of a large hydroelectric plant at Upper Fifteen Mile Falls, a few miles above the existing Lower Fifteen Mile Falls Plant. The only possible water-power sites on the main river below the mouth of the Passumpsic River that have not been developed are at Piermont and Hart Island. There are three existing plants on the main river, namely, at Ryegate, Wilder, and Enfield, that do not have equipment of sufficient capacity to utilize additional flows, and until these plants are redeveloped, no appreciable benefits to them can be realized from future storage reservoirs. On several tributaries of the Connecticut River, there are attractive natural sites for the development of new power stations, but on account of their comparatively small drainage areas and wide variation in natural flows, many of these sites will probably

never be developed. Some of them, however, may become justified after storage reservoirs have been constructed and the flows partially regulated.

65. Prospective future power plants at flood-control dams.- Studies were made of the potential development of hydroelectric power at each of the flood-control dam sites in accordance with the provision of Section 5 of the Flood Control Act of 1936. Reference is made to Section 3 of the Appendix for the detailed analysis at each site. It was found that power development would not be feasible at any site unless conservation storage were provided and a comparatively high head could be obtained from a very high storage dam, or from natural fall below the dam. Assuming that conservation storage were added to that required for flood control up to the physical limits of each reservoir, and that its cost were not charged to power development at the site, the annual return for power was shown to be more than 30 per cent less than the annual cost at all sites except Gaysville and Knightville, where the return was practically equal to the cost, and Newfane, where the return was only 17 per cent less than the cost. Considering that this last value may be within the limits of error of the estimate, provision for penstocks would be justified at Gaysville, Knightville and Newfane, if and when the conservation storage necessary to the development of power at the site is provided. As shown in Section 3 of the Appendix, conservation storage will be feasible at Gaysville and Newfane whenever the existing downstream power plants are augmented by additional power plants, and will not be feasible at Knightville unless part of the cost of the reservoir is borne by a power development at the site.

66. <u>Prospective future storage reservoirs for power storage alone.</u>- Plans have recently been made by the New Hampshire Water Resources Board for the construction of a power-storage reservoir on the Connecticut River at Pittsburg, New Hampshire. This reservoir will have a capacity of about 96,000 acre-feet, the equivalent of about 20 inches of run-off on the uncontrolled area above the proposed dam. Consideration has been given by private interests to the development of a large hydroelectric plant at the Upper Fifteen Mile Falls, which will provide an effective storage capacity of approximately 114,000 acre-feet. Preliminary studies have been given by private interests to the development of a power-storage reservoir on the Moose River at Victory, Vermont, with a capacity of approximately 40,000 acre-feet. The fact that private interests have developed only a limited number of reservoirs would indicate that there are practically no other sites in the basin that can be developed alone and produce sufficient benefits to the power interests at the present time to warrant their cost. The existing storage reservoirs that have been developed by private interests have a measurable flood-controlling effect, and any future additions will increase this effect.

67. <u>Conservation storage developed with flood-control projects.</u>- The function of conservation storage is to store or conserve water when the stream flow is high and to release water when the stream flow is low. Its value is derived from three stages of this process: (1) By storing, it reduces the flow downstream, which may or may not be great enough to cause damage. If conservation storage is not already full at flood times, there will be a value to it from reduction of flood damage; (2) By holding water in storage prior to and during the period of releasing, it provides an artificial lake which may have a recreational value; and (3) By releasing to increase the low-water flow, it aids

in the dilution of sewage, increases industrial water supplies, and increases the power output of run-of-river plants, both utility and industrial. An investigation was made of the relative benefits and costs of providing additional storage for conservation at each of the flood-control reservoirs being considered. Recognition was made of the value to flood control by allowing the use for conservation purposes of one-quarter inch of flood-control storage for each inch of conservation storage added to that required for flood control alone. Recreational values are treated elsewhere in this report. For the third factor, although definite values were determined for the power benefit only, it is believed that the sanitary and industrial aspects are important on some tributaries. The only known method of establishing their values is by negotiation with the parties concerned. At 18 of the 30 recommended and alternate flood-control reservoirs the costs of conservation storage are prohibitive owing to physical conditions. Reference is made to Section 3 of the Appendix for the detailed analysis of the value to power of conservation storage at the remaining 12 sites. It is shown therein that no part of the cost of conservation storage can be borne by power development at the site. However, by increasing the low-water flow in the Connecticut River and its tributaries through the release from conservation storage at the flood-control dams, it was found that the total benefit to all existing and contemplated run-of-river utility power plants would be sufficient to justify economically the construction of additional storage for conservation at ten flood-control dams. A summary of the detailed analysis is shown on Table 14. Column 12 shows the approximate average increase of low-water flow in the lower Connecticut River that would result from the normal operation of conservation storage at each reservoir. If conservation storage is developed

TABLE 14

TABLE

SUMMARY OF POWER BENEFITS TO DOWNSTREAM PLANTS FROM CONSERVATION RESERVOIRS AT FLOOD CONTROL DAMS

SERVOIR		CAPACITIES OF RESERVOIRS							EXISTING DEVELOPMENTS								COMPREHENSIVE DEVELOPMENTS						
		Flood Control		Power Storage		Total				Increased Usable			Annual Value of Increased					Increased Usable		Annual Value of Increased			
Name	Drainage Area Net	Inches	Acre Feet	Inches **	Acre Feet	Inches	Acre Feet	Annual Cost of Power Storage	Accum. Usable Head	Min. Low Water Flow	Peaking Capacity	Yearly Output Thous.	Peaking Capacity	Electric Energy	Total Peaking & Energy	Aver. Cost of Increased Energy per K.W.H.	Accum. Usable Head	Peaking Capacity	Yearly Output	Peaking Capacity	Electric Energy	Total Peaking & Energy	Average Cost of Increased Energy Per K.W.H.
	Sq.Mi.	in.	a.f.	in.	a.f.	in.	a.f.	dollars	ft.	c.f.s.	kw	k.w.h.	dollars	dollars	dollars	mills	ft.	kw	k.w.h.	dollars	dollars	dollars	mills
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
tory	66	7.0	24,600	12.5	44,000	17	59,800	23,200	263.4	146	5640	8,737	33,840	26,211	60,051	2.7	421.0	10,211	15,031	61,266	45,093	106,359	1.5
pton Pond	17.3	7.0	6,500	8.75	8,000	14	12,900	10,000	244.5	26	1021	1,603	6,126	4,809	10,935	6.2	724.3	3,132	4,743	18,792	14,229	33,021	2.1
ysville	226	6.5	77,800	5.5	66,300	10.9	131,200	72,600	170.4	220	6350	9,250	38,100	27,750	65,850	7.8	413.2	15,113	22,460	90,678	67,380	158,058	3.2
ers Brook	30	6.0	9,800	5.0	8,000	10	16,000	18,000	170.4	27	741	1,116	4,446	3,348	7,794	16.1	413.2	1,850	2,702	11,100	8,106	19,206	6.7
st Canaan	80	6.0	25,700	6.25	26,700	11	47,000	14,600	259.4	90	3940	5,660	23,640	16,980	40,620	2.6	715.5	10,900	15,600	65,400	46,800	112,200	0.94
ooker Pond	35	6.0	11,300	5.88	11,000	10.7	20,000	10,000	299.2	36	2036	2,697	12,216	8,091	20,307	3.7	382.0	2,541	3,443	15,248	10,329	25,577	2.9
rkinsville	142	6.0	46,200	11.1	84,000	15.6	118,000	183,000	158.2	282	7530	10,850	45,180	32,550	77,730	16.8	412.8	19,700	28,400	118,200	85,200	203,400	6.4
wfane	326	6.0	105,000	8.3	144,200	12.8	222,500	128,100	98.2	480	7980	11,590	47,880	34,770	82,650	11.1	323.5	26,295	38,180	157,770	114,540	272,310	3.4
iest Pond	19	6.0	6,000	12.5	12,700	17	17,200	18,000	102.2	42.5	737	1,063	4,422	3,189	7,611	16.9	626.3	4,513	6,522	27,078	19,566	46,644	2.8
lly	50	8.0	21,300	12.5	33,300	18	48,000	34,000	85.1	112	1610	2,322	9,660	6,966	16,626	14.6	393.3	7,432	10,733	44,592	32,199	76,791	3.2

Power benefits and annual costs computed on the basis of a capacity of 12.5 inches for power storage, but it is possible that the industrial demand for increased low water flow in the Millers River may justify a higher capacity.

Power Storage = (Total Capacity - Flood Control Capacity) + $\boxed{.25(\text{Total Capacity - Flood Control Capacity})}^{1}$

[1] Max. Value = 3.0" or (Flood Control Capacity - 4.5")

at all ten of the reservoirs the total increase of low-water flow would amount to about 1,460 cubic feet per second. These data can be used as a basis for establishing values, other than for power, which depend upon the conditions and nature of each particular case, and which can not be forecast but may be worked out as each case arises.

68. Comparative economy of power storage at flood-control dams.- The following table shows the estimated annual cost of each reservoir constructed for power storage alone and the corresponding costs with the same capacity of power storage added to flood-control reservoirs at the ten sites where conservation storage appears feasible. In column 6 is shown the difference between the estimated annual cost of reservoirs constructed for power storage alone and the estimated annual cost of the same capacity of power storage constructed in addition to flood-control storage at flood-control reservoirs. Column 7 indicates the ratios between the annual costs given in columns 4 and 5. The economy of power storage in combination with flood control as compared with its cost alone can be seen readily from the table, which shows a saving of 30 to 80 per cent for the former.

TABLE 16
COMPARATIVE ECONOMY OF POWER STORAGE AT FLOOD CONTROL DAMS

Reservoir	Power Storage Capacity		Estimated Annual Costs of Power Storage		Difference between columns 4 and 5	Ratio between columns 4 and 5
	Inches	Acre-feet	For Power alone	Power with flood-control		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Victory	12.5	44,000	$ 51,400	$ 23,200	$ 28,200	2.26
Groton Pont	8.75	8,000	13,800	10,000	3,800	1.38
Gaysville	5.5	66,200	194,000	72,600	121,400	1.60
Ayers Brook	5.0	8,000	51,500	18,000	33,500	2.86
West Canaan	6.25	26,700	105,500	14,600	90,900	7.23
Stocker Pond	5.88	11,000	34,000	10,000	24,000	3.40
Perkinsville	11.1	84,000	280,000	183,000	97,000	1.52
Newfane	8.3	144,200	269,000	128,100	140,900	2.10
Priest Pont	12.5	12,500	36,800	18,000	18,800	2.05
Tully	12.5	33,400	52,000	34,000	18,000	1.53

CONSERVATION FOR RECREATION

69. Importance of recreation.- The Connecticut River Valley is peculiarly adapted by climate and natural features to all types of recreation. For over one hundred years it has been one of the vacation areas of the eastern United States. In addition to the many thousands who spend vacations in the valley there are several times that number who spend week-ends there or visit the Valley as transients. The New England Council and the New Hampshire Planning Board estimate that during the 1936 summer season a total of 791,000 guests spent an average of about 11-1/2 days each, and that about 3-1/4 million transients spent an average of about one day each, a total of about 12 million vacation days, in the Connecticut River Basin areas of the States of Vermont, New Hampshire, Massachusetts, and Connecticut. Considering that within 300 miles of the valley are the large population centers of New York, Brooklyn, Boston, Albany, Philadelphia, Camden, and Newark, and that there is a trend towards devoting more time to recreation, it is reasonable to estimate that there will be a demand for increased recreational facilities in the Valley, the development of which can be economically justified.

70. Value of recreational facilities.- It is estimated by the New England Council that over $400,000,000 was spent by visitors to New England in the summer of 1936, of which more than $276,000,000 was spent in the four states of New Hampshire, Vermont, Massachusetts and Connecticut. Of this amount, $50,863,000 was spent in the Connecticut River Basin. Visitors to New England in 1936 used property valued at more than $500,000,000, of which $63,500,000 was in the Connecticut River Basin, and does not include facilities provided for winter sports visitors. From available statistics on lake resorts in New Hampshire,

it is estimated that the seasonal income from each cottage is about $350, in addition to which each cottage represents to the locality approximately 2,990 vacation days, including transients, from which the net income to the community is approximately $1,088, or a total per cottage per season of $1,438.

71. <u>Determination of reservoirs suitable for recreational conservation.</u>- Each reservoir proposed for the Comprehensive Plan of flood control and the alternates was studied to determine whether additional development for recreation would jeopardize its value for flood control, whether this additional development would be economically justified, and whether the location of, and conditions surrounding the reservoir site would be suitable for a successful recreational development. The decision on this last consideration was aided in several instances by marked local interest in such a project. Based on the amount of suitable shore line which would be made available, and topographic conditions, the number of cottages and other facilities was estimated at those sites which meet the first two requirements, and the number of visitors and estimated net annual income determined therefrom, as indicated in the foregoing paragraph. A comparison of the net annual income with the annual cost of providing the additional storage capacity for recreation shows whether the development for recreation is economically justified. Eight of the 20 reservoirs of the Comprehensive Plan, and three of the alternate reservoirs are considered to have possibilities. At seven of them the additional development which is justified for its power value will also provide a lake for recreational use. General data on the 11 reservoirs are shown on Table 16 which follows. A more detailed treatment of recreational development is given in Section 3 of the Appendix.

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TABLE 16

GENERAL DATA ON

JUSTIFIED RECREATIONAL DEVELOPMENT

Reservoir	State	Shore Line Miles	Flood Control Pool Area Acres (1)	Conservation Pool Area Acres	Estimated Number of Visitors Thru Area Per Summer	Estimated Number of Cottages	Estimated Net Annual Recreational Income	Estimated Annual Recreational Costs (2)
Bethlehem Junction	N.H.	2.7	860	215	225,750	50	117,500(3)	51,500
West Canaan	N.H.	14.7	1,820	1,280	90,000	279	107,000	Cost contained in Power Pool
Stocker Pond	N.H.	18.0	1,150	1,000	100,000	356	134,500	" " " " "
Victory	Vt.	10.0	2,430	2,000	150,000	183	79,000	" " " " "
Groton Pond	Vt.	6.0	855	560	100,000	116	50,500	" " " " "
Union Village	Vt.	3.3	600	280	200,000	47	36,500	1,000
Ayers Brook	Vt.	6.2	720	380	25,000	121	45,000	Cost contained in Power Pool
Gaysville	Vt.	25.0	2,330	1,300	40,000	476	170,500	" " " " "
Newfane	Vt.	23.0	3,180	2,270	55,000	437	158,500	" " " " "
Tully	Mass.	11.5	1,750	1,425	100,000	217	86,000	" " " " "
Priest Pond	Mass.	8.4	900	770	100,000	166	68,000	" " " " "
Total N.H.		35.4	3,830	2,495	415,750	685	359,000	66,100
Total Vt.		73.5	9,915	6,790	570,000	1,380	540,000	1,000
Total Mass.		19.9	2,650	2,195	200,000	383	154,000	41,100
GRAND TOTAL		128.8	16,395	11,480	1,185,750	2,448	1,053,000	108,200

(1) Includes Conservation Pool Area.

(2) Generally when conservation capacity is operated for power storage, no additional construction costs for the dam will be necessary to permit recreation use.

(3) Heavy visitor traffic area already developed.

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PLAN OF IMPROVEMENT

RESERVOIRS

72. Sites studied.- The investigations for this report were aided by previous studies made for the preparation of the 308 Report, published as House Document 412, 74th Congress, 2nd Session, for which nearly 300 sites were investigated, making it possible to reduce intensive studies to a relatively small number of sites. Field investigations and office computations have been made of sites where favorable features appeared to indicate justification for inclusion in a Comprehensive Plan. Some were rejected after a small amount of preliminary work when it became evident that they were not economically justified. Some were considered as alternates until shown to be inferior to other sites controlling similar watershed areas. A list is tabulated on Plate III, which shows the sites that were included in previous reports and the more promising additional sites considered for this report. The following tabulation indicates the 42 sites for which more intensive studies were made:

(Table on following page.)

TABLE 17
LIST OF SITES STUDIED

List No.	Identification No.	Name of Site	Stream		Drainage area above site sq. mi.
1	18A	East Haven*	Passumpsic River,	Vt.	47.5
2	20	Lyndonville	do.		70.0
3	21A	Lyndon Center*	Millers Run (Passumpsic River),	Vt.	52.0
4	22A	Victory*	Moose River (Passumpsic River),	Vt.	66.0
5	50	Harvey Lake*	Stevens River,	Vt.	24.9
6	24A	Bethlehem Jct.*	Ammonoosuc River,	N.H.	90.0
7	51	Franconia	Ham Br.-Gale River(Ammonoosuc R)	N.H.	30.0
8	26	Gale River	Gale River (Ammonoosuc River),	N.H.	56.0
9	68	Sugar Hill	Ammonoosuc River,	N.H.	246.0
10	69	Bath	do.		397.0
11	27A	Groton Pond*	Wells River,	Vt.	17.3
12	28A	South Branch*	South Branch (Waits River),	Vt.	45.0
13	48	Union Village*	Ompompanoosuc River,	Vt.	126.0
14	29A	Gaysville*	White River,	Vt.	226.0
15	30A	Ayers Brook*	Ayers Brook (White River),	Vt.	30.0
16	52	South Randolph	Second Branch (White River),	Vt.	63.0
17	71	North Royalton	do.		72.0
18	49A	South Tunbridge*	First Branch (White River),	Vt.	102.0
19	70	Centerville	White River,	Vt.	692.0
20	67	Hartford	do.		704.0
21	66	West Canaan	Mascoma River,	N.H.	80.0
22	72	Mascoma Lake	do.	N.H.	153.0
23	35A	Bridgewater Corners	Ottauquechee River,	Vt.	101.0
24	63	North Hartland*	do.		222.0
25	53A	Stocker Pond	Stocker Brook (Sugar River),	N.H.	35.4
26	54	Croydon	Croydon Branch (Sugar River),	N.H.	55.0
27	73	Spectacle Pond	do.		65.0
28	64A	Claremont*	Sugar River,	N.H.	245.0
29	36	Ludlow	Black River,	Vt.	56.0
30	37A	Amsden	North Branch (Black River),	Vt.	27.0
31	74	Perkinsville	Black River,	Vt.	142.0
32	55A	N. Springfield*	do.		156.0
33	56A	Cambridgeport	Saxtons River,	Vt.	58.0
34	40A	Newfane*	West River,	Vt.	326.0
35	57A	Surry Mountain*	Ashuelot River,	N.H.	100.0
36	58	Otter Brook	Otter Brook (Ashuelot River),	N.H.	46.7
37	59A	Lower Naukeag*	Millers River,	Mass.	19.7
38	60	Hydeville	do.		85.0
39	61A	Priest Pond	Priest Brook (Millers River),	Mass.	18.8
40	65	Birch Hill*	Millers River,	Mass.	176.0
41	62A	Tully*	Tully River (Millers River),	Mass.	50.0
42	47	Knightville*	Westfield River,	Mass.	164.0

*Included in The Comprehensive Plan.

73. <u>General location of reservoirs in valley</u>.- As stated in Paragraph 28, the run-off from the area above Fifteen Mile Falls does not contribute appreciably to major flood peaks. Therefore, no reservoirs are proposed for that area. Run-off from the area below the watershed of the Farmington River has a negligible effect upon flood stages in the valley, and this area can be excluded also from consideration for the location of reservoirs. The selection of sites for flood-control reservoirs has been limited, therefore, to the critical area from Fifteen Mile Falls to and including the Farmington River. The manner of selection of the reservoirs described below has resulted, to the extent practicable, in their distribution over the entire area so as to make the system effective against a storm centering over any part of the watershed, as well as a general storm.

74. <u>Reservoir locations on tributaries</u>.- The extensive developments of the main river valley prevented the location of flood-control reservoirs on the Connecticut River. The few sites available are suitable for power development only, and do not have sufficient capacity in proportion to their drainage areas to be suitable for flood control. Reservoir sites are limited, therefore, to the major tributaries, and a measure of control has been provided on all tributaries which have had serious flood losses. On the tributaries, the valleys of which have been extensively developed, reservoir sites have been selected on the upper reaches with a view to providing the maximum economically justifiable protection for the developments on the tributaries, as well as for the main river. On the less developed tributaries, reservoirs are located near the Connecticut River in order to control maximum drainage area for the benefit of damage centers on the main stream.

75. <u>Existing partial control</u>.- Reservoirs have not been selected

on the Mascoma, Deerfield, Chicopee, or Farmington Rivers, which already have a degree of control by existing storage developments or storages under construction. The Deerfield River has been extensively developed for power, and the additional sites available are suitable for power development rather than for flood control. The Chicopee River Valley will be afforded some degree of protection by the Quabbin Reservoir now being constructed. The remaining part of the Chicopee Watershed does not have sites suitable for flood-control development at justifiable cost. The Farmington River Valley obtains a degree of control by the Otis, Compensation, and Nepaug Reservoirs, and the cost of additional storage for flood control is excessive in proportion to the benefits that can be obtained.

76. Basis of individual reservoir capacity.- The most economical reservoir capacity for each of the 42 sites investigated was determined as the capacity for which the greatest annual flood-protection benefit in proportion to the annual charges is obtained. All annual benefits referred to herein were obtained as summations of the component benefits in each damage zone below the reservoirs, computed from the interrelation of probable frequency of flood stage to damage, and to its estimated reduction by reservoired storage. This capacity in all cases afforded an adequate control of run-off from the area above the dam site.

77. Basis of selection of reservoirs.- The reservoirs were selected for the Comprehensive Plan so as to provide the most effective flood protection practicable, due consideration being given to the sites available and the economics of the situation. Consideration was given to the relative economic values of the individual reservoirs; to the control of the amount of watershed area desired; and to the geographical distribution of reservoirs to obtain during storms of all

probable types and magnitudes, dependable reduction of flood stages in the middle and lower reaches of the main river.

78. Reservoirs for Comprehensive Plan.- Twenty reservoirs, selected as described, were found to most satisfactorily fulfill the requirements, and are proposed for inclusion in the Comprehensive Plan for flood control, with ten alternates. The estimated total cost of the twenty reservoirs is $34,835,000, of which the cost to the United States for construction will be $24,260,000, and the cost to local interests for rights of way and damages will be $10,575,000. The total effective flood-storage capacity of the twenty reservoirs is 644,500 acre-feet. The drainage area controlled amounts to 2,266 square miles, or 20.1 per cent of the total watershed of the Connecticut River. Thirteen of the reservoirs are located in Vermont and control 1,441 square miles. Three are located in New Hampshire and control 435 square miles; four are located in Massachusetts and control 390 square miles. The reservoirs are distributed among fourteen tributary watersheds of the Connecticut; three reservoirs on each of Passumpsic, White, and Millers, and one on each of Stevens, Ammonoosuc, Wells, Wait, Ompompanoosuc, Ottauquechee, Sugar, Black, West, Ashuelet, and Westfield Rivers. On eleven watersheds the reservoirs will afford local protection, as well as protection below on the Connecticut River. Three reservoirs, one on each of Stevens, Ompompanoosuc, and Ottauquechee Rivers, afford protection on the Connecticut River only. The locations of the reservoirs and the drainage areas controlled are shown on Plate I; their elevations are indicated on the profiles on Plate II. Table 18 shows a summary of data for each reservoir and the group; Table 19, distribution of costs.

TABLE 18
RESERVOIRS OF COMPREHENSIVE PLAN
GENERAL RESERVOIR DATA

Identification No.	Name of Reservoir	Stream	Drainage Area in sq. mi.: Gross above dam	Drainage Area in sq. mi.: Net controlled by dam	Per cent of drainage area of Conn. River controlled by dam	Type of Reservoir Control	Spillway Elevation m.s.l.	Height of dam (feet)	Flood-control capacity: Acre-feet	Flood-control capacity: Inches of run-off	Area at Spillway Elevation (acres)	Cost to United States	Cost to Local Interests	Total Cost of Reservoir	Cost per acre-foot	Cost per sq. mi. of net drainage area
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
18A	East Haven	Passumpsic River .... Vt.	47.5	47.5	0.42	Retarding	1040.0	103	15,500	6.1	500	$ 1,189,000	$ 284,400	$ 1,473,400	$ 95.00	$ 31,000
21A	Lyndon Center	Millers Run (Passumpsic). Vt.	52	52	0.46	Retarding	766.5	79	16,600	6.0	550	776,000	446,500	1,222,500	74.00	23,500
22A	Victory	Moose River (Passumpsic). Vt.	66	66	0.59	Retarding	1149.0	47	24,600	7.0	1,820	367,000	264,000	631,000	26.00	9,600
50	Harvey Lake	Stevens River .... Vt.	24.9	24.9	0.22	Retarding	900.0	37	7,800	5.9	438	163,000	121,100	284,100	36.00	11,400
24A	Bethlehem Junction	Ammonoosuc River.........N.H.	90	90	0.80	Retarding	1356.0	163	28,800	6.0	860	2,146,700	537,400	2,684,100	93.00	29,800
27A	Groton Pond	Wells River .... Vt.	17.3	17.3	0.15	Retarding	1085.0	19	6,500	7.0	560	65,000	51,000	116,000	18.00	6,700
28A	South Branch	South Branch (Waits) .... Vt.	45	45	0.40	Retarding	810.0	95	14,400	6.0	520	489,000	211,000	700,000	49.00	15,600
48	Union Village	Ompompanoosuc River ..... Vt.	126	126	1.12	Gates	543.0	155	30,200	4.5	600	1,726,000	217,900	1,943,900	64.00	15,400
29A	Gaysville	White River .... Vt.	226	226	2.01	Gates	795.0	170	77,800	6.5	1,800	1,725,300	1,725,300	3,450,600	44.00	15,300
30A	Ayers Brook	Ayers Brook (White) ..... Vt.	30	30	0.27	Retarding	695.0	70	9,800	6.0	560	393,000	340,800	733,800	75.00	24,500
49A	South Tunbridge	First Branch (White) .... Vt.	102	102	0.91	Gates	553.0	88	24,500	4.5	750	1,005,000	767,000	1,772,000	72.00	17,400
63	North Hartland	Ottauquechee River ...... Vt.	222	222	1.97	Gates	528.0	153	48,500	4.1	900	2,704,000	158,000	2,862,000	59.00	12,900
64A	Claremont	Sugar River .............N.H.	245	245	2.18	Gates	607.0	105	60,000	4.6	1,370	2,571,000	1,507,000	4,078,000	68.00	16,600
55A	No. Springfield	Black River .... Vt.	156	156	1.39	Gates	519.0	83	26,500	3.2	835	1,057,000	224,200	1,281,200	48.00	8,200
40A	Newfane	West River .... Vt.	326	326	2.90	Gates	486.0	141	105,000	6.0	2,130	3,240,000	1,273,500	4,513,500	43.00	13,800
57A	Surry Mountain	Ashuelot River ..........N.H.	100	100	0.89	Gates	541.0	76	32,000	6.0	1,150	1,295,000	325,100	1,620,100	51.00	16,200
59	Lower Naukeag	Millers River ....Mass.	19.7	19.7	0.17	Gates	1076.0	30	5,400	5.1	650	298,000	131,000	429,000	79.00	21,800
65	Birch Hill	Millers River ....Mass.	176	156.3	1.39	Gates	847.0	59	50,000	6.0	3,150	1,263,000	1,263,000	2,526,000	50.00	16,200
62A	Tully	Tully River (Millers)...Mass.	50	50	0.44	Gates	668.0	65	21,300	8.0	1,125	423,000	150,800	573,800	27.00	11,500
47	Knightville	Westfield River ....Mass.	164	164	1.46	Gates	596.0	140	39,300	4.5	860	1,364,000	576,000	1,940,000	49.00	11,800
				2265.7	20.14				644,500	5.3		$24,260,000	$10,575,000	$34,835,000	$ 54.00	$15,400

TABLE 19
RESERVOIRS OF COMPREHENSIVE PLAN
RESERVOIR COSTS

Identification No.	Name	Total Construction Cost	Lands and Easements	Highway Relocation	Railroad Relocation	Other Public Works Relocation	Total Land and Damages 4+5+6+7	Total Cost 3 + 8	Cost to United States	Cost to Local Interest
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
18A	East Haven	$1,189,000	$102,000	$180,000	None	$2,400	$284,400	$1,473,400	$1,189,000	$284,400
21A	Lyndon Center	776,000	187,000	240,000	None	19,500	446,500	1,222,500	776,000	446,500
22A	Victory	367,000	79,000	185,000	None	None	264,000	631,000	367,000	264,000
50	Harvey Lake	163,000	90,000	30,500	None	600	121,100	284,100	163,000	121,100
24A	Bethlehem Junction	2,146,700	151,000	379,000	None	7,400	537,400	2,684,100	2,146,700	537,400
27A	Groton Pond	65,000	51,000	None	None	None	51,000	116,000	65,000	51,000
28A	South Branch	489,000	59,000	152,000	None	None	211,000	700,000	489,000	211,000
48	Union Village	1,726,000	34,000	182,000	None	1,900	217,900	1,943,900	1,726,000	217,900
29A	Gaysville	1,603,000	402,000	1,433,000	None	12,600	1,847,600	3,450,600	1,725,300	1,725,300
30A	Ayers Brook	393,000	88,000	251,000	None	1,800	340,800	733,800	393,000	340,800
49A	South Tunbridge	1,005,000	306,000	455,000	None	6,000	767,000	1,772,000	1,005,000	767,000
63	North Hartland	2,704,000	158,000	None	None	None	158,000	2,862,000	2,704,000	158,000
64A	Claremont	2,571,000	360,000	528,000	614,000	5,000	1,507,000	4,078,000	2,571,000	1,507,000
65A	North Springfield	1,057,000	150,000	70,000	None	4,200	224,200	1,281,200	1,057,000	224,200
40A	Newfane	3,240,000	396,000	869,000	None	8,500	1,273,500	4,513,500	3,240,000	1,273,500
57A	Surry Mountain	1,295,000	190,000	97,000	None	38,100	325,100	1,620,100	1,295,000	325,100
59	Lower Naukeag	298,000	83,000	48,000	None	None	131,000	429,000	298,000	131,000
65	Birch Hill	845,000	306,000	440,000	896,000	39,000	1,681,000	2,526,000	1,263,000	1,263,000
62A	Tully	423,000	25,000	95,000	None	30,800	150,800	573,800	423,000	150,800
47	Knightville	1,364,000	101,000	475,000	None	None	576,000	1,940,000	1,364,000	576,000
		$23,719,700	$3,368,000	$6,059,500	$1,510,000	$177,800	$11,116,300	$34,835,000	$24,260,000	$10,575,000

79. Drainage area controlled.- The percentage of drainage area controlled by each reservoir, as shown by Table 18, is based upon the entire drainage area of the Connecticut River Watershed. In the following tabulation are shown the percentages of drainage areas controlled by the Comprehensive Plan, and the existing and proposed storage reservoirs in the watershed. The percentage of control for each tributary and the progressive control attained as each tributary joins the main river are indicated:

(Table on following page.)

TABLE 20

SUMMARY OF DRAINAGE AREAS CONTROLLED BY THE COMPREHENSIVE PLAN RESERVOIRS, EXISTING STORAGE AND STORAGE UNDER CONSTRUCTION

River	Drainage Area Sq. Mi.		Controlled Drainage Area Above the Dam Site Sq. Mi.		Ratio of Controlled Drainage Area to Total Drainage Area Per Cent	
	Tributary	Main River Including Tributary	Tributary	Cumulative	Tributary	Main River
Upper Connecticut		1,651	166	166		10.1
Passumpsic	507	2,158	165.5	331.5	32.6	15.4
Stevens	49	2,213	24.9	356.4	50.8	16.1
Ammonoosuc	402	2,629	90	446.4	20.2	17.0
Wells	99	2,728	17.3	463.7	17.5	17.0
Waits	156	3,012	45	508.7	28.8	16.9
Ompompanoosuc	136	3,291	126	634.7	92.7	19.3
White	710	4,068	358	992.7	50.4	24.4
Mascoma	195	4,263	153	1,145.7	78.5	26.9
Ottauquechee	223	4,525	222	1,367.7	99.5	30.2
Sugar	274	4,948	245	1,612.7	89.5	32.6
Black	202	5,231	156	1,768.7	77.4	33.8
Saxtons	78	5,465	-	1,768.7	0.0	32.3
West	423	6,167	326	2,094.7	77.0	33.9
Ashuelot	420	6,667	100	2,194.7	23.8	32.9
Millers	393	7,131	226	2,420.7	57.5	34.0
Deerfield	665	7,839	184	2,604.7	27.7	33.3
Chicopee	724	9,027	187	2,791.7	25.8	30.9
Westfield	520	9,595	209	3,000.7	40.1	31.3
Farmington	613	10,448	112	3,112.7	18.3	29.8
Mouth	-	11,260	-	3,112.7	0.0	27.6

The area below Hartford, or below the watershed of the Farmington River, amounting to about 812 square miles, has a negligible effect upon the flood losses of the valley, and therefore should be disregarded. The area above Fifteen Mile Falls, amounting to 1,650 square miles, not only has a measure of control, but also lies with respect to the valley below it so that it does not contribute to the major peaks, and therefore it, too, may be disregarded. The critical area for the production of flood damages, which is the area tributary to the Connecticut River between Hartford and Fifteen Mile Falls, amounts to about 8,798 square miles, of which the power interests and conservation for domestic water supply afford control, varying from partial to complete, of 681 square miles, or 7.7 per cent. The reservoirs of the Comprehensive Plan control 2,265.7 square miles, or 25.8 per cent of the area. With the plan in operation, a total of 33.5 per cent of the critical area will be controlled.

80. Stage reductions.- The effects of the Comprehensive Plan in the reduction of flood discharges and stage heights of floods such as those of 1927 and 1936 and the Demonstration Flood, described in Section 1 of The Appendix, are shown in Table 21.

(Table on following page.)

TABLE 21

REDUCTIONS IN FLOOD STAGES AND FLOWS BY RESERVOIRS OF THE COMPREHENSIVE PLAN

CONNECTICUT RIVER STATION	Experienced Stage Ft.	Experienced Discharge Thous.cfs	Modified Stage Ft.	Modified Discharge Thous.cfs	Reduction Stage Ft.	Reduction Discharge Thous.cfs
			1927			
White River Jct.	35.0	136.0	25.2	77.0	9.8	59.0
Bellows Falls	303.2	150.5	292.7	72.1	10.5	78.4
Vernon (H. W.)	134.3	159.0	126.4	68.4	7.9	90.6
Montague City	42.8	188.0	31.1	94.3	11.7	93.7
Holyoke	14.8	188.0	9.2	94.3	5.6	93.7
Springfield	22.4	202.0	15.9	116.0	6.5	86.0
Hartford	29.0	181.0	22.0	106.5	7.0	74.5
			1936			
White River Jct.	32.5	120.0	28.0	92.5	4.5	27.5
Bellows Falls	302.2	171.0	295.5	120.4	6.7	50.6
Vernon (H. W.)	137.2	198.5	132.5	135.2	4.7	63.3
Montague City	48.7	247.0	41.3	173.5	7.4	73.5
Holyoke	16.8	247.0	14.1	173.5	2.7	73.5
Springfield	28.3	282.0	23.5	216.0	4.8	66.0
Hartford	37.3	280.0	32.5	222.3	4.8	57.7
		DEMONSTRATION FLOOD				
White River Jct.	35.8	141.3	30.6	107.8	5.2	33.5
Bellows Falls	306.6	202.9	298.2	140.8	8.4	62.1
Vernon (H. W.)	139.7	234.2	134.2	157.8	5.5	76.4
Montague City	52.9	288.7	44.8	207.3	8.1	81.4
Holyoke	17.9	288.7	15.5	207.3	2.4	81.4
Springfield	33.3	351.7	27.4	270.0	5.9	87.7
Hartford	43.8	367.4	38.3	293.0	5.5	74.4

81. Annual cost.- It is assumed that the reservoirs in the Comprehensive Plan will be built by the United States and the several states, and will not be subject to taxation. In accordance with existing instructions, fixed charges are based upon interest rates of 4 per cent for Federal expenditures and 5 per cent for State expenditures. Permanent works are amortized in a period of 50 years. Depreciation is charged against machinery and impermanent elements of the works, based upon lives customarily assigned for the respective elements. Reasonable expenses for operation and maintenance, and the loss of taxes from the land occupied by the reservoirs, are included. The method of computation of the annual cost is explained more fully in Section 4 of The Appendix. The following tabulation shows the annual cost for each reservoir and for the system:

TABLE 22
ANNUAL COSTS
RESERVOIRS OF COMPREHENSIVE PLAN

Identification No.	Reservoir	River		Total Annual Cost
18A	East Haven	Passumpsic River	Vt.	$ 81,700
21A	Lyndon Center	Millers Run (Passumpsic)	Vt.	68,000
22A	Victory	Moose River (Passumpsic)	Vt.	37,800
50	Harvey Lake	Stevens River	Vt.	19,800
24A	Bethlehem Junction	Ammonoosuc River	N.H.	147,000
27A	Groton Pond	Wells River	Vt.	10,200
28A	South Branch	South Branch (Waits)	Vt.	40,300
48	Union Village	Ompompanoosuc River	Vt.	109,900
29A	Gaysville	White River	Vt.	208,400
30A	Ayers Brook	Ayers Brook (White)	Vt.	43,400
49A	South Tunbridge	First Branch (White)	Vt.	102,900
63	North Hartland	Ottauquechee River	Vt.	156,200
64A	Claremont	Sugar River	N.H.	227,200
55A	North Springfield	Black River	Vt.	73,000
40A	Newfane	West River	Vt.	250,900
57A	Surry Mountain	Ashuelot River	N.H.	94,900
59	Lower Naukeag	Millers River	Mass.	28,100
65	Birch Hill	Millers River	Mass.	138,700
62A	Tully	Tully River (Millers)	Mass.	36,000
47	Knightville	Westfield River	Mass.	113,300
				$1,987,700

On the capital investment of $34,835,000 the annual charge of $1,987,700 for the reservoir system is equivalent to 5.7 per cent.

TABLE 23
ALTERNATE RESERVOIRS
GENERAL RESERVOIR DATA

Identification No.	Name of Reservoir	Stream	Drainage Area in sq. mi.		Per cent of drainage area of Conn. River controlled by dam	Type of Reservoir Control	Spillway Elevation m.s.l.	Height of dam (feet)	Flood-control capacity		Area at Spillway Elevation (acres)	Cost to United States	Cost to Local Interests	Total Cost of Reservoir	Cost per acre-foot	Cost per sq. mi. of net drainage area
			Gross above dam	Net controlled by dam					Acre-feet	Inches of Run-off						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
26	Gale River	Gale River (Ammonoosuc)...N.H.	86	86	0.77	Retarding	912.0	92	13,400	2.9	470	$ 833,000	$ 292,200	$1,125,200	$ 84	$13,100
69	Bath	Ammonoosuc River..........N.H.	397	397	3.54	Retarding	600.0	160	127,000	6.0	2,500	4,547,500	4,547,500	9,095,000	72	22,900
70	Centerville	White River.............. Vt.	692	692	6.17	Gates	508.0	175	155,000	4.2	3,300	4,860,000	4,860,000	9,720,000	63	14,000
66	West Canaan	Mascoma River ...........N.H.	80	80	0.71	Gates	893.0	53	25,700	6.0	1,370	888,000	888,000	1,776,000	69	22,200
72	Mascoma Lake	Mascoma River ...........N.H.	153	73	0.65	Gates	759.0	40	17,000	4.4	1,620	471,000	471,000	942,000	55	12,900
53A	Stocker Pond	Stocker Brook (Sugar).....N.H.	35.4	35.4	0.32	Retarding	1032.0	48	11,300	6.0	1,060	254,800	254,800	509,600	45	14,400
36	Ludlow	Black River .... Vt.	56	56	0.50	Gates	1057.0	83	13,400	4.5	640	836,000	641,500	1,477,500	110	26,400
74	Perkinsville	Black River .... Vt.	142	142	1.27	Gates	635.0	119	46,200	6.0	1,350	2,367,000	1,047,000	3,414,000	74	24,000
60	Hydeville	Millers River...........Mass.	85	65.3	0.58	Gates	875.0	65	14,700	4.2	850	604,000	143,600	747,600	51	11,400
61A	Priest Pond	Priest Brook (Millers)...Mass.	18.8	18.8	0.17	Gates	879.0	44	6,000	6.0	500	325,000	97,100	422,100	70	22,400

TABLE 24
ALTERNATE RESERVOIRS
RESERVOIR COSTS.

Identification No.	Name	Total Construction Cost	Lands and Easements 1	Highway Relocation	Railroad Relocation	Other Public Works Relocation	Total Land and Damages 4+5+6+7	Total Cost 3+8	Cost to United States	Cost to Local Interest
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
26	Gale River	833,000	134,000	155,800	None	2,400	292,200	1,125,200	833,000	292,200
69	Bath	1,874,000	2,890,000	1,148,000	3,146,000	37,000	7,221,000	9,095,000	4,547,500	4,547,500
70	Centerville	4,026,000	870,000	1,823,000	2,977,000	24,000	5,694,000	9,720,000	4,860,000	4,860,000
66	West Canaan	411,000	102,000	264,000	993,000	6,000	1,365,000	1,776,000	888,000	888,000
72	Mascoma Lake	361,000	168,000	218,000	[illegible]	None	581,000	942,000	471,000	471,000
53A	Stocker Pond	202,000	73,000	234,000	None	600	307,600	509,600	254,800	254,800
36	Ludlow	836,000	240,000	396,000	None	5,900	641,900	1,477,900	836,000	641,900
74	Perkinsville	2,367,000	271,000	770,000	None	6,000	1,047,000	[illegible]	2,367,000	1,047,000
60	Hydeville	604,000	116,000	24,000	None	3,600	143,600	[illegible]	604,000	143,600
61A	Priest Pond	325,000	21,600	75,900	None	None	97,100	[illegible]	325,000	97,100

82. Annual flood-protection benefits.- The economic evaluation of the reduction in flood stages is given in Paragraphs 43 to 55 herein. The detailed computations are given in Section 2 of The Appendix. The annual flood-protection benefits attributable to the reservoir system have been computed as follows:

Average annual direct benefit..........	$792,000
Average annual indirect benefit........	748,000
Average annual restoration value.......	526,000
Total average annual flood-protection benefit,	$2,066,000

83. Description of reservoirs.- Brief descriptions of the several reservoirs included in the Comprehensive Plan follow. More detailed descriptions, together with cost estimates, are given in Volume 2 of The Appendix.

(1) East Haven - No. 18A.- This reservoir is located on the Passumpsic River, about two miles south of East Haven, Vermont. An earth dam, with a tunnel conduit without gates, will create a retarding basin which will flood an area of about 500 acres at spillway crest. Water will be held back in the reservoir only at times of unusual run-off. The flooded interval will be short, and the normal agricultural pursuits can be carried on within the reservoir area with infrequent and very little interruption. The reservoir will afford reasonable protection for East Burke, Lyndonville, Lyndon, and a considerable measure of protection for St. Johnsbury and other communities on the Lower Passumpsic. The influence upon the Connecticut River will be appreciable. The total cost of the development is estimated at $1,473,400, of which $1,189,000 will be borne by the United States and $284,400 by local interests.

(2) Lyndon Center - No. 21A.- The dam will be on Millers Run, 2-1/2 miles above its confluence with the Passumpsic River, at

Lyndonville, Vermont. It will be of earth, with a tunnel conduit without gates on the right bank. The reservoir will have an area of approximately 550 acres at elevation of spillway lip, and will extend to, but not interfere with the Village of Wheelock. The dam, being of the retarding type, will not impound water except during a most unusual summer flood, and will, therefore, permit continuation of the existing agricultural pursuits within the reservoir area. Operation of the reservoir will afford a high degree of flood protection for the villages of Lyndonville and Lyndon, and for St. Johnsbury, the major flood-damage center on the Passumpsic, as well as yield a measure of flood protection on the Connecticut River. The total cost of the reservoir is estimated at $1,222,500, of which $776,000 will be borne by the United States and $446,500 by local interests.

(3) Victory - No. 22A.- Victory Reservoir site is on the Moose River, 17.3 miles above its junction with the Passumpsic, at St. Johnsbury, Vermont. The dam will be a small earth structure, provided with a conduit without gate control, and will create a lake area of approximately 1,820 acres at spillway elevation. The land which will be flooded is mostly timber and brush, of small agricultural importance. Operation of the reservoir will be of substantial benefit to St. Johnsbury, Vermont, the most important local damage center, and will have some flood-reducing effect upon the Connecticut River proper. The total cost is estimated at $631,000, of which $367,000 will be borne by the United States and $264,000 by local interests. The development of storage for conservation is justified at this site, as discussed in Paragraph 67 herein, at an estimated additional cost of $363,000, or a total cost of $994,000, of which $367,000 would be borne by the United States, and $627,000 by local interests.

(4) Harvey Lake - No. 50.- The Harvey Lake site is on the Stevens River, Vermont, 7 miles above its confluence with the

Connecticut River. The dam will be of earth construction, provided with a conduit without gates. The spillway will be located in a draw adjacent to Harvey Lake, approximately 3/4 mile southeast of the dam. The area of the reservoir at spillway lip elevation will be about 438 acres. Construction of the reservoir will require the relocation of several houses and cottages along the shore of the existing Harvey Lake. The flooding of agricultural lands of any importance will not be required. The total cost is estimated at $284,100, of which $163,000 will be borne by the United States and $121,100 by local interests.

(5) Bethlehem Junction - No. 24A.- Bethlehem Junction Reservoir is located well up on the Ammonoosuc River, at the foothills of the White Mountains. The dam site is about 3-1/2 miles east of Bethlehem, New Hampshire. An earth dam, with a tunnel conduit in the right bank, without gates, will create a retarding basin, which will flood an area of about 860 acres at the spillway crest. The area flooded will be submerged for only comparatively short intervals. The reservoir will provide a considerable measure of flood protection for Littleton and the several villages below on the Ammonoosuc, and will have appreciable flood-reducing effect upon the Connecticut River. The total cost is estimated at $2,684,100, of which $2,146,700 would be borne by the United States and $537,400 by local interests. A pool, about 1-1/2 miles long, 1/2 mile wide, containing an area of about 210 acres, for recreational purposes during the summer season, can be provided at an additional cost to local interests of $752,000.

(6) Groton Pond - No. 27A.- The Groton Pond reservoir site is on the headwaters of the Wells River, Vermont, 16-1/2 miles above its junction with the Connecticut River. The drainage area controlled by this reservoir is the smallest of any considered. The dam will be of

concrete, with ends of rock-fill construction. The outlets will not be provided with gates. The reservoir will have an area of about 560 acres at spillway lip elevation. The moving of several houses and cottages to higher ground will be necessary. There will be no agricultural lands involved. The total cost is estimated at $116,000, of which $65,000 will be borne by the United States and $51,000 by local interests. The development of storage for conservation is justified at this site, as discussed in Paragraph 67 herein, at an estimated additional cost of $144,000, or a total cost of $260,000, of which $65,000 would be borne by the United States and $195,000 by local interests.

(7) <u>South Branch - No. 28A.</u>- South Branch Reservoir is located on the South Branch of Waits River, about one and one-half miles above its confluence with Waits River. The dam site is about three miles northeast of South Corinth, Vermont. An earth dam, provided with a reinforced concrete conduit without gates, will create a retarding basin three miles long at the elevation of the spillway crest. The flooded area of 520 acres is largely wooded, and the operation of the reservoir, flooding the reservoir for only short intervals, will reduce its present value little, if any. The reservoir will provide a considerable degree of flood protection for the lower part of the Waits River Valley, including the Village of Bradford, and will have an appreciable effect upon the Connecticut River for the benefit of those communities located on the Connecticut below the mouth of Waits River. The total cost is estimated at $700,000, of which $489,000 will be borne by the United States and $211,000 by local interests.

(8) <u>Union Village - No. 48.</u>- The Union Village reservoir site is on the Ompompanoosuc River, Vermont, 4.1 miles above its confluence with the Connecticut River. The dam will be of earth construction, with a funnel spillway, and outlet tunnel with gate control.

The reservoir will have an area of about 600 acres at spillway lip elevation and will extend to, but not interfere with the Village of Thetford Center. The land to be acquired for the reservoir is of minor agricultural importance. Operation of the reservoir will be for the reduction of flood peaks in the main valley of the Connecticut River. The total cost is estimated at $1,943,900, of which $1,726,000 will be borne by the United States, and $217,900 by local interests.

(9) Gaysville - No. 29A.- The Gaysville Reservoir site is on the White River, Vermont, 31.6 miles above its junction with the Connecticut River. The dam will be a concrete arch, and will be provided with a spillway and four outlet conduits controlled by valves. The reservoir will cover an area of approximately 1,800 acres at spillway lip elevation, and will submerge some areas of agricultural importance as well as some important highways. Operation of this reservoir will benefit several important flood-damage centers on the White River, and have important flood reducing effect on the Connecticut River. The total damage costs exceed the estimated construction cost, primarily on account of the extensive road relocation made necessary. The total cost is $3,450,600 of which the construction cost is $1,603,000, land and damages $1,847,600. One-half will be borne by the United States and one-half by local interests. The development of storage for conservation is justified at this site, as discussed in Paragraph 67 herein, at an estimated additional cost of $1,329,400, or a total cost of $4,780,000, of which $1,725,300 would be borne by the United States, and $3,054,700 by local interests.

(10) Ayers Brook - No. 30A.- This reservoir site is on Ayers Brook, 1.2 miles above its junction with the Third Branch of the White River, Vermont. The dam will be of earth construction and provided on the right bank with a conduit without gates. The area of the

reservoir at spillway lip elevation will be about 560 acres. This level will be reached only during unusual floods which rarely occur during the crop-growing season. Operation of the reservoir will be primarily for the benefit of flood-damage centers on the White River. The total cost of the reservoir is $733,800, of which $393,000 will be borne by the United States and $340,800 by local interests. The development of storage for conservation is justified at this site, as discussed in Paragraph 67 herein, at an estimated additional cost of $295,200, or a total cost of $1,029,000, of which $393,000 would be borne by the United States, and $636,000 by local interests.

(11) South Tunbridge - No. 49A.- The dam site is on the First Branch of the White River, about 1-1/4 miles above its junction with the White River, approximately 19-1/2 miles above the confluence of the White and Connecticut Rivers. The dam will be of earth, with a side-channel spillway on the left bank, and a conduit, provided with gate control, on the right bank. The reservoir, at spillway lip elevation, will cover approximately 750 acres, and will flood the Village of South Tunbridge and extend to, but not interfere seriously with, the Village of Tunbridge. Operation of the reservoir will benefit local flood-damage centers on the White River, as well as have a flood-reducing effect on the Connecticut River proper. The total estimated cost is $1,772,000, of which $1,005,000 will be contributed by the United States and $767,000 by local interests.

(12) North Hartland - No. 63.- The North Hartland reservoir site is on the Ottauquechee River, Vermont, about 1-3/4 miles above its junction with the Connecticut River. The dam will be of earth, with a side-channel spillway and a conduit outlet with gates on the left bank. The reservoir area at spillway lip elevation will

be approximately 900 acres, and will extend to, but not seriously interfere with, Dewey's Mill near Quechee, Vermont. Land required for the reservoir area is mostly covered with wood and brush and is of small agricultural importance. The site of the dam has been acquired by the New England Power Association for the construction of power storage. The operation of the reservoir will have an excellent flood-controlling effect along the main stem of the Connecticut River. The total estimated cost is $2,862,000, of which $2,704,000 will be borne by the United States and $158, 000 by local interests.

(13) Claremont - No. 64A.- The location for this reservoir is on the Sugar River just upstream from Claremont, New Hampshire, about 6.7 miles above the junction of the Sugar and Connecticut Rivers. The dam will be of earth, with a side-channel spillway and a gate controlled conduit on the left bank. The reservoir will cover an area of about 1,370 acres at spillway lip elevation, and will require the purchase of farming lands of considerable importance. The relocation of important highways, as well as 3 miles of the Claremont Branch of the Boston & Maine Railroad will be necessary. Operation of the reservoir will have an important flood-reducing effect upon the local damage center of Claremont, as well as being of material importance for the reduction of the Connecticut River flood stages. The total estimated cost is $4,078,000 of which $2,571,000 will be borne by the United States and $1,507,000 by local interests.

(14) North Springfield - No. 55A.- The reservoir will be on the Black River, 8-1/4 miles above its junction with the Connecticut River. The dam will be of earth and concrete, with gate control. The reservoir will cover about 835 acres at spillway lip

elevation, and will not require the purchase of lands of agricultural or industrial importance. Operation of the reservoir will have an important flood-reducing effect at the major flood-damage center of Springfield on the Black River, as well as a material effect in reducing flood stages on the Connecticut River. The total cost is estimated at $1,281,200, of which $1,057,000 will be borne by the United States and $224,200 by local interests.

(15) Newfane - No. 40A.- The Newfane reservoir site is on the West River, Vermont, 10.8 miles above its junction with the Connecticut River. The dam will be of earth, with a side-channel spillway and a tunnel conduit with gates on the right bank. The reservoir will cover an area of about 2,130 acres at spillway lip elevation. Construction of the reservoir will require the purchase of agricultural lands of major importance, as well as abandonment of the small Village of Harmonyville. Considerable and extensive highway relocation will be necessary. The operation of the reservoir, which controls a drainage area of 326 square miles, the largest of any reservoir considered, will have considerable flood-reducing effect at Brattleboro and other major flood-damage centers on the Connecticut River. The total cost is estimated at $4,513,500, of which $3,240,000 will be borne by the United States and $1,273,500 by local interests. The development of storage for conservation is justified at this site, as discussed in Paragraph 67 herein, at an estimated additional cost of $2,566,500, or a total cost of $7,080,000, of which $3,240,000 would be borne by the United States, and $3,840,000 by local interests.

(16) Surry Mountain - No. 57A.- The reservoir site is located on the Ashuelot River, New Hampshire, 34.6 miles above its junction with the Connecticut River. The dam will be of earth

construction, with a side-channel spillway and conduit with gate control on the right bank. The reservoir at spillway lip elevation, will cover about 1,150 acres, of which the major portion is of agricultural importance. Operation of the reservoir will have a major flood-reducing effect at Keene, New Hampshire, and other local damage centers on the Ashuelot River, and will give a reasonable measure of control for the reduction of floods on the Connecticut River. The total cost of the reservoir is estimated at $1,620,100, of which $1,295,000 will be borne by the United States and $325,100 by local interests.

(17) Lower Naukeag - No. 59A.- Lower Naukeag Reservoir is located on the headwaters of the Millers River about four miles east of Winchendon, Massachusetts. The dam consists of an earth-fill section and a concrete section for spillway and outlet gates across Millers River; a dike across the existing outlet of Lower Naukeag Lake; and a long dike over the low ground at the westerly side of the lake. The flooded area will include about 400 acres beyond the limits of the existing Lower Naukeag Lake. The Lower Naukeag Reservoir will provide flood-protection for Winchendon and the communities below on the Millers River, where heavy damages were suffered from the 1936 flood. It will provide some degree of protection on the Connecticut River below Turners Falls. The total estimated cost is $429,000, of which $298,000 will be borne by the United States and $131,000 by local interests.

(18) Birch Hill - No. 65.- The Birch Hill Reservoir is located on Millers River, about 26-1/2 miles above its junction with the Connecticut River. The dam site is about one mile northeast of South Royalston, Massachusetts. An earth dam across the main channel, supplemented by two earth fills, one in an abandoned railroad cut, and

the other in a low saddle now occupied by the railroad, will create a reservoir flooding about 3,150 acres at the spillway crest. The outlet will be controlled by a Tainter gate 22 feet wide by 27 feet high. The reservoir capacity of 50,000 acre-feet will provide for a 6.0-inch run-off from the net drainage area of 156.3 square miles below Lower Naukeag Reservoir. The reservoir will provide a large degree of flood protection for the benefit of the communities below South Royalston, on the Millers River, and a considerable measure of relief will be extended to the Connecticut River below Turners Falls. The total cost is estimated at $2,526,000, of which $1,263,000 will be borne by the United States and $1,263,000 by local interests.

(19) Tully - No. 62A.- This reservoir is located on Tully River, about 3.9 miles above its confluence with Millers River. An earth dam will be constructed across the main channel, a spillway will be provided in the adjacent saddle on the left bank, and an outlet tunnel will be drilled through rock of the left abutment. The reservoir will extend upstream about 2-1/2 miles, flooding about 1,125 acres, mostly covered with woods and brush. The reservoir will have an excellent storage capacity, provision being made for eight inches of run-off from the 50 square miles of drainage area. It will provide a high degree of flood protection to the communities on Millers River from Athol to Millers Falls, and will afford a measure of benefit on the Connecticut River below Turners Falls. The total cost of the development is estimated at $573,800, of which $423,000 will be borne by the United States and $150,800 by local interests. This site affords an opportunity for providing conservation storage in addition to the flood storage, as discussed in Paragraph 67. For the development of a net conservation storage of 38,700 acre-feet, in addition to the flood storage proposed above, the

additional cost is estimated at $855,200.

(20) Knightville - No. 47.- Knightville Reservoir is located on the Westfield River, about 27-1/2 miles above its junction with the Connecticut River. The 164-square-mile watershed above the dam site has a leaflike shape, comprising several relatively long streams. The dam site is in the upper limits of the Village of Knightville, Massachusetts. The dam will consist of an earth fill, with a gravity concrete overflow section for a spillway. At the spillway crest the reservoir will extend upstream about six miles, flooding about 860 acres, including a number of buildings and a small cemetery. Less than one-half the reservoir area is cultivated; a considerable part is not cleared. This reservoir will provide a considerable degree of flood protection for the several communities on the Westfield River below the dam site, including West Springfield and Springfield, on the Connecticut River. It will appreciably reduce the high stages of the Connecticut River to the benefit of the communities on that stream below Springfield. The total cost is estimated at $1,940,000, of which $1,364,000 will be borne by the United States and $576,000 by local interests.

84. Alternate reservoirs.- In selecting the reservoirs proposed for the project group, described in the foregoing paragraphs, it is recognized that certain of the other sites studied merit almost equal consideration for one or the other of the following reasons:

(a) Very nearly equal economic justification and the possibility that local cooperation may be provided more readily than for some of the preferred sites, in which case the alternate should be adopted to expedite providing flood protection.

(b) The suitability of the site for valuable conservation storage which local interests may desire to have developed at their expense, and the value of which may outweigh the present apparent economic deficiency.

(c) Superior area control, but excessively expensive local cooperation required, for which, however, with further study, a solution may be developed which will increase flood protection values.

The ten sites considered as alternates are as follows:

(1) Gale River - No. 26.- Gale River reservoir site is on Gale River, about 2.8 miles above its junction with the Ammonoosuc River. The dam site is about three miles northwest of Franconia, New Hampshire. While this reservoir would have a capacity of only 2.9 inches of run-off from a drainage area of 86 square miles, it merits consideration and study for the influence it can have in connection with Bethlehem Junction reservoir in alleviating flood damage on the Ammonoosuc below the mouth of Gale River, and because it also would have some measure of benefit on the Connecticut River. The dam would consist of an earth-and-rock-fill structure across the main river and a small dike on the right bank. A side-channel spillway and a tunnel in rock would be provided on the right bank. The tunnel would not be provided with gate control. The reservoir area at spillway-crest elevation 912.0 m.s.l. would be about 470 acres, and would extend upstream to, and inundate a few houses in the downstream part of the Village of Franconia. Ordinary agricultural pursuits could be maintained in the upper part of the reservoir, which would not be flooded during the summer months except in rare cases of unusually heavy rainfall. The total cost of the development is estimated at $1,125,200, of which $833,000 would be borne by the United States and $292,000 by local interests.

(2) Bath - No. 69.- Bath reservoir site is located on the Ammonoosuc River, about 3.1 miles above its confluence with the Connecticut River. The dam site is about two miles southwest of Bath, New Hampshire. This reservoir would control 397 square miles, or

99 per cent, of the Ammonoosuc River drainage area, which, together with its proximity to the Connecticut River, would make it very effective in alleviating flood damage on this main river at Woodsville and other communities, especially above the White River. An earth dam with a side-channel spillway and a tunnel in rock on the right bank without gate control would create a retarding basin, which, at spillway-crest elevation 600.0 m.s.l., would cover about 2,500 acres. The full reservoir would extend upstream about ten miles, flooding portions of the Villages of Bath and Lisbon, and extensive railroad and highway relocation would be required. The reservoir would not be flooded in the summer season except during unusual run-offs, and agricultural pursuits could, therefore, be continued for the greater part of the reservoir area. The total cost of the development is estimated at $9,095,000, of which $4,547,500 would be borne by the United States and $4,547,500 by local interests.

(3) Centerville - No. 70.- The Centerville reservoir site is located on the White River, about six miles above its junction with the Connecticut River. The dam site is about one mile southwest of West Hartford, Vermont. This reservoir would have a capacity of 4.2 inches of run-off from a drainage area of 692 square miles. The capacity and large drainage area controlled would make this reservoir very effective in reducing flood heights for the benefit of Hartford and White River Junction, on the White River, and damage centers on the Connecticut River below White River Junction. It would be a very effective substitute for the Gaysville, Ayers Brook, and South Tunbridge reservoirs, but would not give protection on the upper reaches of the White River. The development, consisting of a concrete and earth dam with a spillway crest at elevation 508 m.s.l., would create a reservoir about 17.5 miles long, extending

upstream to beyond the mouth of the Second Branch of the White River. The reservoir would inundate habitations at the Villages of West Hartford and Sharon, and dike protection would be required for the Villages of South Royalton and Royalton. Extensive relocation of the Central Vermont Railroad and the main highway along the White River would be required. The total cost of the development is estimated at $9,720,000, of which one-half would be borne by the United States and one-half by local interests. The cost per square mile of drainage area controlled is $14,000, or less than the average cost per square mile controlled for the recommended reservoir system.

(4) West Canaan - No. 66.- The West Canaan reservoir site is located on the Mascoma River, about 19.5 miles above its confluence with the Connecticut River. The dam site is about 1-1/2 miles east of West Canaan, New Hampshire. The reservoir would control a drainage area of 80 square miles, would have a capacity of six inches of run-off, amounting to 25,700 acre-feet, and would provide protection for the Villages of West Canaan, Enfield, and Lebanon, on the Mascoma River, and have a considerable flood-reducing effect upon the Connecticut River below White River Junction. The dam would be a gravity type concrete structure with an overflow spillway section across the main channel and a gate section on the right bank. The reservoir would extend about four miles up the Mascoma River and about two and one-half miles up the Indian River. The flooded area would be about 1,370 acres, about one-third of which is low hay land, and the remainder is brush and swamp land. The Boston & Maine Railroad and a state highway would require relocation. The total cost of the development has been estimated at $1,776,000, of which $888,000

would be borne by the United States and $888,000 by local interests. The estimate has been prepared without foundation borings, and should be considered as preliminary only. Development of conservation storage to the extent of five inches of run-off is justified at this site, as discussed in Paragraph 67 herein, and can be obtained at an additional estimated cost of $244,000.

(5) Mascoma Lake - No. 72.- This reservoir site is located on the Mascoma River, about ten miles above its junction with the Connecticut. The dam site is about two miles west of Enfield, New Hampshire, at the outlet of the existing Mascoma Lake. The development would replace the existing power storage owned by the Mascoma River Improvement Co., and provide an additional flood-storage capacity of about 2.1 inches of run-off from the 153 square miles of drainage area. The reservoir, in connection with the West Canaan reservoir, would provide effective control against any flood run-off on the Mascoma River, and provide a considerable flood-reducing effect on the Connecticut River below White River Junction. The estimate is based upon a dam consisting of a gravity-type concrete overflow section and a concrete gate section in the main channel, with an earth-fill section on the right bank. At the spillway-crest elevation, 759 m.s.l., the lake surface would be about eight feet higher than its normal level. At the lowest draw-down, elevation 737, the lake surface would be about 6-1/2 feet below the lower limit of the existing development. Operation of the reservoir would be conducted in such a manner as to retain the present lake level, as nearly as is practicable to do so, during the tourist season when the cottages around the lake are occupied. The total cost is estimated at $942,000, of which $471,000 would be borne by the United States and $471,000 by local

interests. The estimate has been prepared without foundation borings, and should be considered as preliminary only.

(6) Stocker Pond - No. 53A.- Stocker Pond reservoir site is on Stocker Brook, tributary to Croydon Branch of the Sugar River, New Hampshire. The dam would be of earth, with a spillway and conduit without gates on the right bank. The pool area at spillway-lip elevation would be about 1,060 acres, of which a major part is now occupied by Stocker Pond. The additional area to be acquired is of small agricultural importance, but several houses and cottages on the lake front would have to be acquired or moved to higher ground. The operation of the reservoir would reduce flood heights on the Sugar River, and would produce a small effect upon the flood stages of the Connecticut River proper. In the event that the Claremont Reservoir, located just above Claremont, on the Sugar River, should be built, the construction of Stocker Pond should not be considered. The total cost is estimated at $509,600, of which $202,000 is the construction cost and the cost of land and damages is $307,600. One-half the total cost, or $254,800, would be borne by the United States. The development of storage for conservation is justified at this site, as discussed in Paragraph 67 herein, at an estimated additional cost of $82,400, or a total cost of $592,000, of which $254,800 would be borne by the United States and $337,200 by local interests.

(7) Ludlow- No. 36.- The Ludlow reservoir site is on the Black River, Vermont, 28 miles above its junction with the Connecticut River. The dam would be of earth, with a side-channel spillway, and a conduit with gate-control on the right bank. The reservoir would cover about 640 acres at spillway-lip elevation; would extend to the small Village of Tyson; and would cover Rescue Lake, including several

summer cottages at or near this lake. The area within and below spillway elevation is of considerable importance as a summer resort and for recreational purposes. Operation of the reservoir would be so conducted as to avoid any interference with the present use of the reservoir area except during unusual and extreme summer floods. The flood-reducing effect at local damage centers on the Black River would be considerable, and there would be some flood-controlling effect on the Connecticut River proper. The total cost is estimated at $1,477,500, of which $836,000 would be borne by the United States and $641,500 by local interests.

(8) Perkinsville - No. 74.- The Perkinsville reservoir joins two separate basins, one on the Black River, beginning about 12.5 miles above its confluence with the Connecticut River; the other on the North Branch about 2.7 miles above its mouth. North Branch is tributary to the Black River about one mile below Perkinsville, Vermont. The dam site on the Black River is about 0.3 mile north of Perkinsville; that on the North Branch is at the Village of Amsden, Vermont. The Perkinsville site would be suitable for construction as a substitute for the North Springfield reservoir. It offers possibilities for the construction of additional storage, for power purposes and for recreational facilities, if required by local interests. The drainage area that would be controlled is 142 square miles, or 14 square miles less than the drainage area above the North Springfield dam site. The cost per acre-foot, and per square mile of drainage area controlled, is considerably higher than for the North Springfield reservoir, and it should be developed only if unexpected difficulties appear at the North Springfield site. The flood protection afforded would be considerable for flood-damage centers on the Black River below Perkinsville, and the flood-reducing

effect on the Connecticut River would be appreciable. Construction would involve an earth-fill dam, with a gate-control tunnel in the right bank, at the Perkinsville dam site; and a gravity concrete dam, with an open overflow spillway and an open outlet conduit through the spillway section, at the Amsden dam site. These dams, supplemented by two low dike sections, one in each of the ridges forming the North Branch below Amsden, would provide storage capacity for a run-off of six inches from the total drainage area of 142 square miles. The total cost of the development is estimated at $3,414,000, of which $2,367,000 would be borne by the United States and $1,047,000 by local interests. Rock is visible at the left abutment and surface features indicate that rock rises beneath the right abutment. Borings have not been made, however, and the estimate should be considered to be preliminary. Additional storage for conservation as discussed in Paragraph 67 herein, to the extent of 9.6 inches of run-off or 71,800 acre-feet, can be developed at an additional cost of $3,383,000.

(9) Hydeville - No. 60.- The Hydeville reservoir site is located on the Millers River, about one mile west of Waterville, Massachusetts. The reservoir, with a flood-storage capacity providing for about 2.3 inches of run-off from the 85 square miles of drainage area, would yield considerable flood protection for the communities located on the Millers River below Waterville, and would afford some reduction of flood stages on the Connecticut River. The Hydeville reservoir and the Priest Pond reservoir would be acceptable as substitutes for construction in place of the Birch Hill reservoir on the Millers River near South Royalston if unexpected difficulties should develop in connection with the latter site. The Hydeville dam would consist of an earth fill across the main channel, supplemented by two short dike sections on the right bank, one dike section in a small sag, the

other (including a concrete spillway section) in a saddle far into the right bank. The dam would create a reservoir flooding about 850 acres at spillway-crest elevation, 875 m.s.l. The reservoir would extend upstream to the lower limits of the Village of Waterville on the Millers River, and would flood the sewage-disposal plant belonging to the Town of Winchendon. One arm of the reservoir would extend north up Sip Pond Brook as far as the Massachusetts-New Hampshire state line, and would flood the two small Villages of Bullardsville and Harrisville. In order to provide a better outlet foundation, the gate sill would be placed at elevation 840 m.s.l.; this would create a permanent pond covering about 140 acres. The pond might be useful for recreational purposes. The total cost of development is estimated at $747,600, of which $604,000 would be borne by the United States and $143,600 by local interests.

(10) Priest Pond - No. 61A.- Priest Pond reservoir site is located on Priest Brook about 3.1 miles above its junction with the Millers River. Priest Brook is tributary to Millers River, about 29.7 miles above the confluence of the Millers and the Connecticut Rivers, and 2.7 miles below the Hydeville dam site. The reservoir, with a capacity providing for a 6.0-inch run-off from the 18.3 square miles of drainage area, would yield a fair degree of flood protection for the communities along the lower two-thirds of the Millers River, where much damage resulted from the 1936 flood. Some flood-control effect would be produced on the Connecticut River proper. The reservoir should be constructed only in the event that the Birch Hill development is abandoned. The construction at the Priest Pond site would consist of a rolled-earth dam, with a concrete overflow spillway section and a Tainter gate outlet on the right bank. The reservoir would extend upstream about three miles, flooding about 500 acres at the

spillway-crest elevation, 879 m.s.l. Most of the reservoir area is covered with second-growth brush, and is of small value. The total estimated cost is $422,100, of which $325,000 would be borne by the United States and $97,100 by local interests. Additional storage for conservation as discussed in Paragraph 67 herein, to the extent of 18 inches of run-off, or 18,000 acre-feet, can be developed at an additional cost of $685,300.

DIKES

85. Existing dikes provided by local interests.- State, municipal, and private interests have provided local protection by means of dikes at various points along the Connecticut River in Massachusetts and Connecticut. There are no existing dikes in the Connecticut Valley in the States of Vermont and New Hampshire. The height of existing dikes varies with the locality, but, in most cases, they have been constructed to an elevation to give protection against a flood of the magnitude of that which occurred in November 1927. In general, existing works provide for drainage within the dike system by means of intercepting sewers and pumping plants. The March 1936 flood topped all dikes in the Connecticut Valley. In a few rural areas in the State of Massachusetts, dikes have been constructed to prevent destructive erosion of fertile farm lands but do not provide protection from inundation of land at high stages of the river.

86. Dikes under construction by the United States.- As a result of the great damage caused by the 1936 flood, a number of existing dikes are being raised and extended by the Engineer Department, with local cooperation, as work relief projects in accordance with the provisions of the Flood Control Act of 1936. This work is now practically complete.

87. Expenditures for existing dikes.- The total cost of the existing dikes is approximately $2,200,000 of which approximately $775,000 has been expended by State and local interests in Massachusetts and $1,425,000 in Connecticut. The report submitted by the District Engineer of the Providence District, on January 31, 1935, Subject: Report on preliminary examination of the Connecticut River, with a view to the control of its floods and prevention of erosion of its banks in the State

of Massachusetts, (File No. 7402 (Conn. R.) 29), approximates the expenditures for protective works in Massachusetts as $930,000, which also includes expenditures for prevention of bank erosion. The allotments providing for dike construction now being done as relief work by the United States total $425,000. Pertinent data in connection with existing dikes will be found in Section 5 of the Appendix. Existing works are indicated on Plate No. 140 in Section 7 of the Appendix.

88. Unsuitability of dikes for the upper Connecticut Valley.- Flood protection by the construction of dikes without reservoirs has been studied throughout the entire Connecticut Valley. These studies have shown little or no justification for dikes in the upper Valley in the States of New Hampshire and Vermont. The principal reasons are: (a) In general, the values subject to damage by floods are scattered over a wide area, not concentrated in populous centers; consequently, dike protection would need to be very extensive, requiring expenditures far in excess of benefits. (b) The few more populous centers subjected to heavy flood losses are mill towns, in which the industries are located in such a manner on the bank of the river as to make dike construction impracticable at a cost in proportion to the value of protection. (c) The inhabitants of the upper Valley have made no efforts to protect themselves. There has been no local agitation for dikes. It would appear that were dikes a practical means of protection their necessity would have been realized after the devastating flood of 1927, as dikes, where they are practicable, are know to be an effective means of local protection.

89. Suitability of dikes for parts of the lower Connecticut Valley.- In the lower Connecticut Valley in the States of Massachusetts and Connecticut dikes have greater merit because: (a) There are a number

of highly developed industrial and commercial centers which have suffered severe losses in recent floods and for which dike protection is practicable. (b) There have been concerted efforts by a number of municipal and private interests to protect, with dikes, valuable areas subjected to flooding. This is shown by the existing dikes described in Paragraph 1, and in Section 5 of the Appendix which lists all existing works. (c) There are a few dikes on the lower side of bends which protect rural areas from destructive erosion and silting during periods of flood. Some additional dikes might be justified for this purpose at a few widely scattered localities, but the protective value would be relatively small. Dikes protecting rural and suburban areas for purposes other than to prevent erosion and silting of farm land are not justified, because of the scattered low values that would be protected in the narrow width of the Valley and the numerous brooks and streams entering into the river, which would necessitate extensive dikes along these small tributaries or expensive pumping and drainage facilities to provide normal drainage during flood periods.

90. Effect of extensive dike system on velocities and stages.- The construction of a system of dikes through any considerable portion of the Valley, particularly in sections outside of highly developed areas where there is considerable overbank flow, would increase velocities in the channel causing destructive bank erosion and requiring extensive bank protection. Furthermore, such a system of dikes by elimination of valley storage and overbank flow within the protected area would materially increase flood heights, requiring higher and more expensive dikes.

91. Estimated cost and relative value of system of dikes.- For the reasons given in Paragraph 88, no estimates have been prepared for dikes without reservoirs as a means of flood protection in the States

of Vermont and New Hampshire, or in the entire Valley. In order, however, to determine a measure of the justification for dikes alone, estimates of cost have been prepared for protection by dikes at the seven cities and towns in Massachusetts and Connecticut which suffered the greatest individual losses in the flood of March 1936, and for the area flooded by the Connecticut River below the northern boundary of Massachusetts. The estimate for dike protection of these seven localities to the elevation of the maximum predicted flood amounts to approximately $19,000,000, which includes the costs of construction, rights of way, and the necessary drainage and pumping facilities. These dikes would protect areas that suffer about 38 per cent of the total average annual direct losses of the entire Valley, and would have additional benefits in the preservation of property values, and in the maintenance of the social security of the communities protected. Studies for protection of the entire flooded area along the lower River in Massachusetts and Connecticut indicate that the relation of costs to benefits increases very rapidly when considering protection of other localities in addition to the seven stated. For a total estimated expenditure of $43,000,000, approximately 50 per cent of the average annual direct flood losses in the entire valley can be prevented. In other words, with an expenditure for dikes alone equal to approximately 90 per cent of the cost of the Comprehensive Plan for reservoirs and dikes, as hereinafter recommended, only about one-half of the annual direct benefits of the Comprehensive Plan would be obtained. Therefore, the construction of dikes throughout the entire Connecticut Valley as a sole means of protection is not considered worthy of detailed study.

92. Basis of value for dikes in addition to reservoirs.- The system of reservoirs proposed in the Comprehensive Plan will reduce the

magnitude of great floods and the frequency of all destructive floods to the extent of providing practical protection to the greater portion of the Connecticut Valley. However, a study of the elevations of the March 1936 flood and the greatest predicted flood as compared to ground elevations of the flooded areas indicates that a greater degree of protection than that afforded by reservoirs is needed in certain highly developed industrial, commercial and residential areas. In such localities, the value of dike protection, in addition to that provided by reservoirs, is based on the following: (a) Additional direct benefits from the prevention of recurring direct losses as indicated by the frequency-damage relations. (b) Additional indirect benefits approximately equal in value to the direct benefits. (c) Savings by stabilization of property values and the restoration of depreciated property values to the pre-flood levels plus insurance of social security to the entire community through stabilization of industrial and business pursuits thus preventing the possibility of general withdrawal of manufacturing or commercial concerns from the flooded area and municipality.

93. Localities studied.- Flood control by the construction of protective dikes supplemental to a system of reservoirs has been studied in all areas of concentrated values where damages caused by historic floods were large, and where it is expected that the value of the area protected and consequent benefits would be sufficient to justify the expense in addition to the proportional part of the reservoir expense, or where evidence that the stability of the community might be adversely affected by continuance of the flood loss threat. Detailed studies for dikes were consequently confined to the lower Connecticut Valley in the States of Massachusetts and Connecticut because of the fact that,

of the Boston and Albany Railroad bridge and from the Memorial Bridge to the South End Bridge. The intervening land between the bridges is above flood stage. The dike now being enlarged above the North End Bridge provides the northern link to high ground. The proposed protection will consist of earth dike, concrete wall, or raising of railroad subgrade, the type used being the most economical for the particular section of work. Drainage during flood periods will be maintained by pumping plants of sufficient capacity to dispose of all storm and sanitary sewage within the protected area. Mill River will be carried through a pressure conduit of sufficient area to handle the maximum predicted discharge of the stream. The flood protection works will be constructed to the Comprehensive Plan design grade and will protect an area of 819 acres. The estimated cost of the project is $1,814,000 of which $590,000 is the cost to the United States for construction, $66,000 is for rights of way and damages, and $1,158,000 is for drainage and pumping stations. The total annual cost of the proposed project is $132,000, and the annual benefit is $11,700 in direct benefits, $12,600 in indirect benefits, and in excess of $905,000 in the preservation of normal values.

(5) The increases in flood heights and velocities that will result from the construction of the proposed plan have been computed and are considered negligible.

(6) Local interests have stated that they are in favor of the proposed plan of protection, and will comply with the requirements of the Flood Control Act of 1936, and with the departmental policies requiring municipalities benefitted to provide the required pumping and drainage facilities.

d. <u>West Springfield, Massachusetts.</u>

(1) The Town of West Springfield is located on the west

TABLE 25

GENERAL DIKE DATA

Locality	Type of Dike	Approx. Height of Dike (Feet)	Approx. Length of Dike (Feet)	Approx. Area Protected (Acres)	Character of Area Protected	Assessed Valuation of Area Protected	Total Direct Flood Losses in Area Protected (1936)	Cost to United States for Construction	Costs to Local Interests: Rights of Way and Damages	Costs to Local Interests: Pumping Plants and Drainage Appurtenances	Costs to Local Interests: Total	Total Cost	Ratio Total Cost to Assessed Valuation (Per Cent)	Ratio Total Cost to 1936 Direct Flood Loss (Per Cent)
Hartford	Concrete wall & earth fill	20	21,000	2,755	Railroad industrial commercial residential	$135,600,000	$7,330,000	$4,700,000	$315,000	$525,000	$840,000	$5,540,000	4.1	75.6
East Hartford	Earth fill & concrete wall	20	15,000	582	Railroad commercial residential	8,454,000	1,324,000	845,500	202,500	233,000	435,500	1,281,000	15.2	96.8
Springfield	Earth fill & concrete wall	10	12,000	819	Railroad industrial commercial residential	75,329,000	3,701,000	590,000	66,000	1,158,000	1,224,000	1,814,000	2.4	49.0
West Springfield	Earth fill & concrete wall	12	16,800	1,044	Industrial commercial residential	16,048,000	2,854,000	225,000	11,000	30,000	41,000	266,000	1.7	9.3
Chicopee	Earth fill & concrete wall	10	24,000	1,020	Industrial commercial residential	5,909,000	871,000	680,000	58,000	569,000	627,000	1,307,000	22.1	150.1
Holyoke	Concrete wall & earth fill	10	17,400	105	Industrial residential	11,720,000	774,000	1,203,500	123,500	160,000	283,500	1,487,000	12.7	192.1
Northampton	Earth fill & concrete wall	15	11,600	175	Small commercial residential	2,716,000	438,000	318,000	39,000	115,000	152,000	470,000	17.3	107.5
TOTAL			117,[illegible]00	6,500		$255,776,000	$17,292,000	$8,562,000	$815,000	$2,788,000	$3,603,000	$12,165,000	4.8	70.4

95. Summary of costs.- The foregoing table lists the total cost of the proposed dikes at $12,165,000 of which $8,562,000 is the cost to the United States for construction, $815,000 is for rights of way and damages, and $2,788,000 is for drainage and pumping facilities. The estimates of cost for dikes and appurtenant works are listed in detail in Section 5 of the Appendix.

96. Relation of benefits to costs.- The justification for the proposed dike work is based upon the Value of Protection as discussed in paragraph 55. The total benefits accruing from the dikes are the sum of the benefits derived from the prevention of direct and indirect recurring losses not accredited to the reservoir system plus the benefits derived from the stabilization of property values within the protected area and the insurance of social security through stabilization of industrial and business pursuits. The average annual costs of the work are composed of the carrying charges on the capital investment by Federal and local interests, plus costs of maintenance and operation, plus loss of taxes on lands transferred to municipal ownership. The following table lists the localities studied in order of relative merit based on the relation of benefits to costs.

TABLE 26

RELATION OF ANNUAL BENEFITS TO ANNUAL COSTS

Locality	Total Average Annual Benefits (Dollars)	Total Average Annual Costs (Dollars)	Ratio Benefits to Costs
West Springfield	204,300	14,900	13.71
Springfield	929,300	132,000	7.04
Hartford	1,701,500	313,100	5.43
Holyoke	144,240	86,500	1.67
East Hartford	120,300	80,700	1.49
Chicopee	76,000	84,900	.90
Northampton	26,360	29,200	.90
Total	3,202,000	741,300	4.32

1,821,900
1,380,200

97. Description of proposed dikes.- The general plans upon which the foregoing estimates are based are briefly described in the following paragraphs. A more detailed discussion will be found in Section 5 of the Appendix.

a. Hartford, Connecticut.

(1) The City of Hartford is situated on the west bank of the Connecticut River, 52 miles above the mouth. It is one of the principal industrial and commercial cities on the Connecticut River, the capital of the State of Connecticut and is the insurance center of the United States. The city covers 17.4 square miles and had a population of 164,072, in the 1930 census.

(2) In the section north of Park River a large railroad distribution yard and an extensive industrial area along the Connecticut River are subject to flooding. An important industrial section and an airport were damaged when the 1936 flood overtopped the Colt and Clark Dikes and flooded the area south of Park River. The flood waters also backed up the Park River and flooded valuable commercial property east of Main Street and in the heart of the city. Records of the losses sustained in floods prior to March 1936 are not complete but recent investigations show the direct loss caused by the 1936 flood to have been $7,330,000.

(3) The section of the city south of Park River is protected against frequent floods of the Connecticut River by two dikes known as the Colt Dike, built by Colonel Samuel Colt about 1855, to approximately 31 feet above mean sea level, and the Clark Dike, built by the City of Hartford in 1930 and 1931 to approximately 33 feet above sea level. These dikes were overtopped by the flood of March 1936 about five feet and three feet respectively, and are now being raised and

enlarged to the Comprehensive Plan design grade by the United States as a work relief project under the policies of the Flood Control Act of 1936.

(4) The proposed dike protection consists of an earth dike, or concrete flood wall where rights of way cannot be economically obtained. The dike alignment parallels the Connecticut River bank from the enlarged portion of the Colt Dike to a point about 14,000 feet north of the Memorial Bridge and thence west to high ground near the Windsor Town line. Concrete flood walls are proposed to confine the Park River to its channel and prevent backwater from the Connecticut River in time of flood. The protection will be constructed to the Comprehensive Plan design grade and will protect 2,755 acres, largely of highly developed industrial and business property. Drainage will be maintained during flood stages by intercepting sewers and three pumping plants along the Park River, and one pumping plant in the North Meadows. The estimated cost of the protection is $5,540,000, of which $4,700,000 is the cost to the United States for construction, $315,000 is for rights of way and damages, and $525,000 is for drainage and pumping stations. The total annual cost of the proposed plan of dike protection is $313,100, and the annual benefit is $29,300, in direct benefits, $32,200 in indirect benefits, and in excess of $1,640,000 in the preservation of normal values.

(5) The increases in flood heights and velocities that will result from the construction of the proposed plan have been computed and are considered negligible.

(6) The foregoing indicates the extent to which the United States is justified in providing flood protection. Improvements desired by local interests are much more elaborate and extensive, including the construction of a river front boulevard and a city

beautification scheme. Local interests propose to meet the additional expense with the expectation that the United States will stand the equivalent of the cost of flood control only. It is believed reasonable that the United States participate to the extent of the cost of construction of the dike and flood walls.

b. East Hartford, Connecticut.

(1) The Town of East Hartford is situated on the east bank of the Connecticut River, 52 miles above the mouth and directly across from the City of Hartford. The town has a number of manufacturing concerns, a population in the 1930 census of 17,125 and covers 18.2 square miles.

(2) The area subject to frequent flooding is a low plain sloping gently to a swale at the foot of a bluff upon which are located the main business and residential sections which were partially flooded for the first time during the flood of March 1936. The development on the low plain is principally low-cost residences and small business establishments with the exception of a bulk oil station. The flooded portion of the bluff area consists principally of medium priced residential property. The actual amounts of losses sustained in floods prior to March 1936 are not available but recent investigations show that the 1936 flood caused a direct loss of $1,324,000 to the property for which protection is proposed.

(3) There are no existing flood protection works at East Hartford; however, a flood protection project was approved August 30, 1935, Public #409, 74th Congress. A modification of this project was recommended in "Report on Flood Control of the Connecticut River, at East Hartford, Connecticut," dated January 15, 1937. (F.C. 35-1/51).

(4) The proposed plan of protection is an earth dike with

a concrete flood wall where lack of space prevents the economical use of an earth section. The dike will be built to the Comprehensive Plan design grade and will protect approximately 582 acres. The dike alignment begins at high ground north and adjacent to the New York, New Haven and Hartford Railroad and runs along the railroad embankment to the Connecticut River, thence south along the river to a point beyond the inhabited area, thence east to the bluff and thence along the north bank of the Hockanum River to high ground. Drainage will be maintained during flood stages by intercepting sewers and two small pumping plants along the Connecticut River, and one larger plant in the swale at the south dike line. The estimated cost of the protection is $1,281,000, of which $845,500 is the cost to the United States for construction, $202,500 is for rights of way and damages, and $233,000 is for drainage and pumping stations. The total annual cost of the proposed dike protection is $80,700, and the annual benefit is $9,000 in direct benefits, $10,000 in indirect benefits, and in excess of $101,300 in the preservation of normal values.

(5) The increases in flood heights and velocities in the Connecticut River that will result from the construction of the proposed plan have been determined and are provided for by raising the grade and providing riprap at locations subject to scour. The increased cost of other protective works and increased damages caused by the increased back-water effect of the East Hartford dike have been included in the annual charges against the East Hartford protection.

(6) Local interests are in favor of the proposed plan of protection but desire the United States to bear the total cost in accordance with the project approved August 30, 1935 which provides that the entire cost, not to exceed $658,000, will be borne by the United States. It has been indicated, however, that the town is willing to

comply with the Flood Control Act of 1936 if exception is made to the departmental policy requiring localities benefitted to provide drainage and pumping facilities.

c. Springfield, Massachusetts.

(1) The City of Springfield is located on the east bank of the Connecticut River about 76 miles above the mouth. The principal industry is manufacturing, the more important products being electrical equipment, textiles, hardware and sporting goods. The city had a population of 149,900 in the 1930 census, and covers an area of 31.7 square miles.

(2) The areas subject to great floods are the lower sections adjacent to the river. These areas are largely utilized by railroads, industrial plants, commercial establishments and low cost residences. A small area in the main business section of the town was flooded during the 1936 flood. The flood damages from historic floods are not available, but recent investigations show that the direct loss caused by the flood of March 1936 was $3,701,000.

(3) The north residential section of the town is protected against floods of the Connecticut River by an earth dike which extends from high ground about 3,000 feet above the Chicopee city line to the North End Bridge over the Connecticut River. This structure was rebuilt after the 1936 flood as a local work relief project to protect against floods of the magnitude of the 1927 flood. It is now being raised and enlarged to the Comprehensive Plan design grade by the United States as a work relief project under the terms of the Flood Control Act of 1936.

(4) The proposed plan of protection is the construction of a dike extending from the North End Bridge to the high ground north

of the Boston and Albany Railroad bridge and from the Memorial Bridge to the South End Bridge. The intervening land between the bridges is above flood stage. The dike now being enlarged above the North End Bridge provides the northern link to high ground. The proposed protection will consist of earth dike, concrete wall, or raising of railroad subgrade, the type used being the most economical for the particular section of work. Drainage during flood periods will be maintained by pumping plants of sufficient capacity to dispose of all storm and sanitary sewage within the protected area. Mill River will be carried through a pressure conduit of sufficient area to handle the maximum predicted discharge of the stream. The flood protection works will be constructed to the Comprehensive Plan design grade and will protect an area of 819 acres. The estimated cost of the project is $1,814,000 of which $590,000 is the cost to the United States for construction, $66,000 is for rights of way and damages, and $1,158,000 is for drainage and pumping stations. The total annual cost of the proposed project is $132,000, and the annual benefit is $11,700 in direct benefits, $12,600 in indirect benefits, and in excess of $905,000 in the preservation of normal values.

(5) The increases in flood heights and velocities that will result from the construction of the proposed plan have been computed and are considered negligible.

(6) Local interests have stated that they are in favor of the proposed plan of protection, and will comply with the requirements of the Flood Control Act of 1936, and with the departmental policies requiring municipalities benefitted to provide the required pumping and drainage facilities.

d. <u>West Springfield, Massachusetts.</u>

(1) The Town of West Springfield is located on the west

bank of the Connecticut River, 76 miles above the mouth and directly across from the City of Springfield, and north of and adjacent to the Westfield River. A number of small manufacturing concerns and the Eastern States Exposition grounds are located in the area adjacent to the Westfield River. The town had a population of 16,684 in the 1930 census, and covers an area of 16.8 square miles.

(2) The area subject to floods of the Connecticut River is an alluvial plain sloping gently away from the Connecticut River toward the Westfield River. Practically all of the main residential district and the industrial concerns are located in this area and were inundated by the flood of March 1936. The amounts of the flood damages sustained prior to the 1936 flood are not available, but recent investigations show that the loss caused by the 1936 flood was $2,854,000.

(3) An existing earth dike provides protection against frequent floods of the Connecticut River for the low area along the Westfield River but was overtopped about 3.5 feet by the flood of March 1936. From high ground north of the North End Bridge to the Memorial Bridge a dike is being constructed to the Comprehensive Plan design grade by the United States as a work relief project in accordance with the provisions of the Flood Control Act of 1936.

(4) The proposed plan of protection consists of an earth dike. This dike will be constructed to the Comprehensive Plan design grade and will provide protection for about 1,044 acres. The dike alignment begins at high ground south of the Memorial Bridge, runs south along the bank of the Connecticut River to the mouth of the Westfield River, and thence west along the bank of the Westfield River to high ground about 3,000 feet above the Agawam Bridge. Drainage of the protected area during flood stages will be maintained by existing pumping plants, with the addition of a small pumping plant and intercepting

sewer proposed north of the North End Bridge. The total estimated cost of the proposed protection is $266,000, of which $225,000 is the cost to the United States for construction, $11,000 is for rights of way and damages, and $30,000 is for drainage and pumping station. The total annual cost of the proposed protection is $14,900 and the annual benefit is $5,850 in direct benefits, $6,450 in indirect benefits and in excess of $192,000 in the preservation of normal values.

(5) The increases in flood heights and velocities in the Connecticut River that will result from the construction of the proposed plans for West Springfield and Springfield have been computed and are not considered serious.

(6) Local authorities are in full accord with the proposed plan of flood protection and are prepared to comply without delay with the requirements of the Flood Control Act of 1936, and to provide the drainage and pumping facilities required by departmental policies.

e. Chicopee, Massachusetts.

(1) The City of Chicopee is situated on the east bank of the Connecticut River, 80 miles above its mouth. The Chicopee River divides the city into two parts. The principal industry is manufacturing, leading products being radio and electrical goods, rubber products and sporting goods. The city covers 22.9 square miles and the population by the 1930 census was 43,930.

(2) The area subject to great floods of the Connecticut River include a medium priced residential section and several important industries in the alluvial plain along the river from the Willimansett section southerly to the Chicopee River, a highly developed industrial section along the south bank of the Chicopee River, and a small industrial

section along the Connecticut River immediately above the Springfield City line and included in the proposed dike protection for the City of Springfield. The amounts of the flood damages sustained prior to March 1936 are not available, but recent investigations show that the loss caused by the 1936 flood was $871,000.

(3) A dike recently constructed as a work relief project by local interests to the approximate grade of the 1927 flood provides protection to that stage for the area north of the Chicopee River.

(4) The proposed plan of protection for the City of Chicopee is a system of dikes protecting the extended area north of Chicopee River and the industrial section along the south bank of Chicopee River. Earth dikes are proposed except where lack of space makes it necessary to construct a concrete flood wall. The dikes will be constructed to the Comprehensive Plan design grade and will protect about 1,000 acres north of and 20 acres south of Chicopee River. The dike protection begins at high ground in the Willimansett section, proceeds southerly along the bank of the Connecticut River to the mouth of the Chicopee River, and thence easterly to high ground beyond the Boston and Maine Railroad. On the south bank of Chicopee River the dike begins at the lower dam, runs westerly along the Chicopee River to a short distance below the Boston and Maine railroad and thence southerly and easterly to high ground. Drainage of the protected areas during flood stages of the Connecticut River will be provided for by five pumping stations placed at points of natural drainage or at existing sewers for the area north of Chicopee River and by small units in the industries along the south bank of the river. The estimated cost of the proposed protection is $1,307,000, of which $680,00 is the cost to the United States for construction, $58,000 is for rights of way and damages, and $569,000 is for drainage and pumping stations. The total

annual cost of the proposed work is $84,900 and the annual benefit afforded by the protection is $2,280 in direct benefits, $2,520 in indirect benefits, and in excess of $71,200 in the preservation of normal values.

(5) The increases in flood heights and velocities in the Connecticut River that will result from the construction of the proposed dikes have been computed and are considered negligible. Only a small percentage of the channel floodway is within the protected area.

(6) Local authorities favor the proposed plan for flood protection, except that they desire that the plan be modified to include flood protection for the Hampden Brewing Company at the northerly end of Chicopee and for the Turner Falls Power and Electric Company located on the south bank of the Chicopee River at its junction with the Connecticut River. These properties have not been included in the plan of protection because of the established policy of the United States not to protect individuals nor single interests. Local participation is dependent upon the interest shown by manufacturers and other parties desiring protection, however, it is the belief of local authorities that the requirements of local participation will be met.

f. <u>Holyoke, Massachusetts</u>.

(1) The City of Holyoke is situated on the west bank of the Connecticut River, 85 miles above the mouth. It is a highly developed industrial city, the principal products being paper and paper products. It had a population of 56,537 in the 1930 census, and covers an area of 20.9 square miles.

(2) The area subject to great floods is the low narrow plain adjacent to the river. This zone is entirely utilized, with the exception of a small tenement residential section, by industrial plants

and the railroad facilities which serve them. Actual damages sustained in floods prior to that of March 1936 are not available, but recent investigations show the direct loss caused by the 1936 flood was $774,000.

(3) Existing flood protection works consist of the Springdale Dike, built after the 1927 flood by the City of Holyoke, and designed to protect a residential and tenement section in the south section of the city against floods of the magnitude of the 1927 flood. This earth dike proved inadequate for the major flood of March 1936 and is now being raised and enlarged to the Comprehensive Plan design grade by local interests as a work relief project.

(4) The dikes of the proposed plan of protection will extend from the extreme upstream damage zone at the Holyoke dam, downstream along the west bank of the river to the Springdale Dike now being enlarged. Certain portions of the bank line are of such height that dikes are not required. Breaks in the dike alignment occur at the uncontrolled overflows from the high level canals where the dikes will extend inland along the banks of these overflows to the high ground. The numerous tailrace tunnels will be provided with gates to prevent backwater from the Connecticut River entering the protected area during flood periods. These gates will be integral parts of the dike structure. Earth dikes will be used where economical, but owing to the topographical features and lack of space, the greater portion of the protection will be concrete flood walls of the cantilever type. Drainage within the protected area during flood stages will be provided for by the construction of intercepting sewers and installation of pumping facilities. The flood protection works will be constructed to the Comprehensive Plan design grade and will protect an area of approximately 105 acres. The estimated cost of the project is $1,487,000, of which $1,203,500 is the cost to the United States for construction, $123,500 is for rights of

way and damages, and $160,000 is for drainage and pumping stations. The total annual cost of the proposed project is $86,500, and the annual benefit is $1,570 in direct benefits, $1,670 in indirect benefits, and in excess of $141,000 in the preservation of normal values.

(5) Increases in flood heights and velocities in the Connecticut River resulting from the proposed structures have been computed and are considered negligible. The natural flood plain has been almost completely utilized by industrial buildings, and the channel restriction by the proposed dike is small and does not materially reduce the floodway area.

(6) Local interests have stated by letter that they are in favor of the proposed plan of protection, will comply with the requirements of the Flood Control Act of 1936, and will provide for the necessary drainage and pumping facilities in accordance with departmental policies.

g. Northampton, Massachusetts.

(1) The City of Northampton is situated on the west bank of the Connecticut River, 94 miles above the mouth. The city is an educational center, a health resort city and has a number of small industries. The total population was 24,381 in the 1930 census, and the area is 34.6 square miles.

(2) The area subject to frequent flooding is a low plain along the Connecticut River with an area of about 3,500 acres, is located east and south of the main business and residential portion of the city, and is used largely for farming purposes. However, a more highly developed section is located at the point where Mill River enters the low plain in its course to the Connecticut River. This development, for which protection is proposed, includes a small residential section, a number of small commercial establishments, and the municipal gas plant.

The amounts of flood losses sustained in floods prior to March 1936 are not available but recent investigations indicate that the direct loss within the proposed protected area due to the 1936 flood was $438,000.

(3) An existing dike along the south bank of Mill River, which was constructed by a private dike company in 1856-57 and enlarged in 1869, affords protection against floods of the magnitude of that of 1927 but was overtopped about 6 feet in the flood of March 1936. This dike protects about 66 acres having an assessed valuation of about $509,000.

(4) (a) The proposed plan of protection is a system of earth dikes with concrete flood walls where lack of space prohibits the use of an earth section. The dikes will be built to the Comprehensive Plan design grade and will protect about 109 acres north of Mill River and about 66 acres south of Mill River. The dike alignment north of Mill River proceeds from high ground near Pomeroy Terrace and Hancock Street along the open meadowland, east of the main business district to the Mill River and thence northerly along Mill River to high ground at the New South Street Bridge. South of Mill River the alignment begins at high ground near the heart of the city, proceeds downstream to the Boston and Maine Railroad and south along the railroad to the existing dike and thence to high ground. A short section of earth dike extends upstream along the east bank of Mill River from the New York, New Haven, and Hartford Railroad embankment to high ground near Smith College. Drainage of the protected area will be maintained during flood stages of the Connecticut River by siphon ejectors south of Mill River, and an intercepting sewer to a pumping plant north of Mill River. The estimated cost of the protection is $470,000, of which $318,000 is the cost to the United States for construction, $39,000 is for rights of way and damages, $113,000 is for drainage and pumping stations. The

annual cost of the proposed plan of dike protection is $29,200, and the annual benefit is $2,690 in direct benefits, $2,770 in indirect benefits, and in excess of $20,700 in the preservation of normal values.

(b) An alternate plan for flood protection has been advocated by certain local interests. The plan consists of an earth dike beginning near Pomeroy Terrace and Hancock Street, and following along the proposed alignment to Hockanum Road, then extending directly across Mill River to the intersection of the Boston and Maine railroad with the existing lower dike, then along the existing dike to high ground. Under this plan the flow from Mill River will be diverted into the Connecticut River through Ox Bow Lake by a diversion canal to be excavated along the low ground lying between a point on the Mill River a short distance below the New York, New Haven and Hartford railroad bridge and Ox Bow Lake. The cost of this plan is estimated at 10 to 25 per cent more than for the plan proposed.

(5) Since the dikes are situated in close proximity to high ground and protect a relatively small area, the overbank floodway of the Connecticut River is not materially reduced and the effects on flood heights and velocities in the Connecticut River are negligible.

(6) The proposed plan indicates the extent to which the United States is justified in providing flood protection, however, the city has advised that funds are not at present available for local participation. Certain local interests have submitted for consideration the alternate plan wherein Mill River is diverted from the central part of the city and which has many features in addition to flood control that make it a more attractive plan to the city. If, in the future, local interests desire to bear the excess cost of the alternate plan and it is determined to be an effective practicable plan from the stand-

point of flood control, it is believed reasonable that the United States participate to the extent of the cost of construction of the proposed plan.

(Report continued on following page)

CHANNEL IMPROVEMENTS

98. Localities studied.- The Connecticut River was examined to find all reaches in which there appeared to be any natural constriction or obstruction of the flood channel. As a result the following four locations were selected for study:

Middletown Narrows below Hartford, Connecticut

Pecowsic Narrows below Springfield, Massachusetts

Smith Ferry Narrows above Holyoke, Massachusetts

Wells River Bar at Wells River, Vermont.

Reference is made to Section 6 of the Appendix for the detailed analysis at each location studied and a brief summary of each is given below. At a number of places where loss from bank erosion appeared most probable, protection has been provided through the activities of the Civilian Works Administration and the Commonwealth of Massachusetts, and through work relief projects prosecuted under the United States Engineer Department. The reduction of overbank flows by the reservoirs will further greatly reduce the likelihood of bank erosion, and expenditure by the United States for bank protection as part of the flood control project other than that recommended in connection with the construction of dikes is not justified.

99. Middletown Narrows below Hartford, Connecticut.- The reach of river studied extends from Enfield Rapids to Paper Rock, below Middletown, a total distance of 41 miles, special attention being given to the 24 miles from Hartford to Paper Rock. In the upper reach, including Hartford and extending to Gildersleeve Island, the valley is more than a mile wide and the flood slope is uniformly about 0.3 foot per mile. In the remaining eight miles to Paper Rock the valley gradually narrows, swings from its previous southerly direction towards the southwest and then gradually turns eastward until below Middletown it has taken an easterly direction. The

average flood slope in this reach is 0.9 foot per mile, part of the fall being concentrated at the "Straits" between Bodkin Rock and Paper Rock.

100. In the 24 miles from Hartford to Paper Rock occur the greatest flood losses in the state. Two-thirds of the fall in this reach is concentrated in the bend and constriction below Gildersleeve Island. Any reduction of the flood slope in this reach would lower flood stages at Hartford, Middletown, and adjacent areas. The topography lends itself to two possible methods of effecting such a reduction, for which studies were made and plans prepared, termed herein Plan A and Plan B.

101. Plan A provides for enlarging the flood channel at Bodkin Rock about 18 per cent and straightening the shore line on the left bank of the "Straits" about 2.2 miles below Middletown. This plan would provide a uniform cross-sectional area of 40,000 square feet below the 1936 flood level by excavating about 8,400 cubic yards of earth and about 394,300 cubic yards of rock at a total estimated cost of $832,200. This would provide a reduction in flood stage of 1.28 feet at Middletown and 0.43 foot at Hartford for a flood equal to that of March 1936. The reduction of average annual direct loss would be $30,150 if this plan alone is considered, but with the reservoirs of the Comprehensive Plan proposed herein in operation the reduction of average annual direct loss by Plan A would be only $7,000. Since the annual carrying charge would be $38,760, it is seen that channel improvement by Plan A is not warranted if the Comprehensive Plan proposed herein is adopted.

102. Plan B provides for an auxiliary flood channel to be excavated across the bend from Gildersleeve Island to a point about 800 feet below Paper Rock. The total length of the channel would be 4.0 miles, while the corresponding distance by river around the bend is 7.6 miles. It is estimated that this plan, involving the excavation of over a million cubic yards of rock and 37 million cubic

yards of earth, and requiring the relocation of highways, transmission lines, and a railroad, would cost $13,992,000. For a flood equal to that of March 1936, 35 per cent of the discharge would be diverted down this channel, thereby lowering the flood stage 2.60 feet at Middletown, 2.12 feet at Hartford, and lesser amounts upstream, its effect being dissipated over the Enfield Rapids. The reduction of average annual direct loss would be $103,260 if this plan alone is considered, but with the Comprehensive Plan in operation it would be only $22,050. Since the annual carrying charge, including maintenance, would be about $713,892, it is seen that this plan can not be justified either by itself or as a part of any flood control plan.

103. The possibility of excavating only a pilot channel at the location of Plan B and of depending on flood flows to scour out a channel of sufficient cross section to produce appreciable stage reductions has been considered. However, the uncertainty of obtaining such reductions and the certainty of injuring the navigable channel eliminate further consideration of this alternate plan despite its low initial cost.

104. Pecowsic Narrows below Springfield, Massachusetts.- The reach of river studied extends from the foot of Holyoke Dam to the lower end of the Pecowsic Narrows below Springfield, a total length of about 13 miles, special attention being given to the lower 4 miles below North End Bridge, Springfield, where the greatest flood losses have been suffered. The river flows through this lower portion with a flood slope of about 1.00 foot per mile and at Pecowsic Point enters a restricted section known as the Narrows, through which the flood

slope is about 1.66 feet per mile.

105. Reduction of this flood slope would lower the flood levels at Springfield and Chicopee and points upstream as far as the foot of Holyoke Dam. The best means of producing such reduction by enlargement of the flood channel is the removal of Pecowsic Point. Two plans of enlargement of varying degree were studied and are herein termed Plan A and Plan B.

106. Plan A provides a minimum cross-sectional area of 46,400 square feet below the 1936 flood level through the Narrows by excavating about 2,025,700 cubic yards of earth and about 239,100 cubic yards of rock at a total estimated cost of $1,233,900. As a result of this enlargement a flood as great as that of March 1936 would be reduced 0.46 foot at Springfield and 0.25 foot at Chicopee. The reduction of average annual direct loss would be $15,970 if this plan alone were in operation, and $3,965 if reservoirs of the Comprehensive Plan were in operation. Since the annual carrying charge is $27,600 it is seen that this plan is not justified either alone or as a part of any flood control plan.

107. Plan B provides a minimum cross-sectional area of 39,200 square feet below the 1936 flood level by excavating about 294,300 cubic yards of earth and about 35,200 cubic yards of rock at a total estimated cost of $193,000. As a result of this enlargement a flood as great as that of March 1936 would be reduced 0.16 foot at Springfield and 0.10 foot at Chicopee. The reduction of average annual direct loss would be $4,825 if this plan alone were in operation and $1,325, if the reservoirs of the Comprehensive Plan were in operation. Since the annual carrying charge is $8,994, it is seen that this plan is

not justified either alone or as a part of any flood control plan.

108. Smith Ferry Narrows above Holyoke, Massachusetts.- The reach of river studied extends from the highway bridge at Northampton to the Holyoke Dam, a distance of 11 miles. About 5.1 miles below Northampton bridge the river flows through a gap in the Holyoke Range and the width of the flood channel is reduced abruptly from over 1-1/2 miles to about 1/2 mile. About 26 miles below this gap the river enters the restricted section known as Smith Ferry Narrows and occupies the entire valley width of about 700 feet. This restricted section is 1.4 miles long and terminates in the pool of the Holyoke Dam. In March 1936 the flood slope from Northampton Bridge to the gap in Holyoke Range was 0.37 foot per mile; from the gap to the Narrows, 1.00 foot per mile; and through the Narrows, 6.1 feet per mile.

109. The channel restriction at the Narrows appears to be a major factor in backing flood waters up to Northampton since more than two-thirds of the total fall in the eleven mile reach occurs in this restricted section. Reduction of the flood slope through the Narrows would lower flood stages at points upstream, including Northampton. Enlargement of the flood channel seems the best way of effecting such slope reduction. Two plans, designated Plan A and Plan B, were studied.

110. Plan A provides for such enlargement by widening the banks and excavating to low water level. A minimum cross-sectional area below the 1936 flood level of 20,100 square feet, an increase of 25 per cent, would be provided by the excavation of about 37,000 cubic yards of earth and about 335,000 cubic yards of rock, at an estimated total

cost of $591,700. For a flood equal to that of March 1936 the crest stage would be reduced 3.09 feet immediately above the enlargement and 2.09 feet at Northampton. The reduction of average annual direct loss would be $10,800 if this plan alone is considered, and $1,095 if the reservoirs of the Comprehensive Plan were in operation. Since the annual carrying charge would be $27,600, it is seen that Plan A is not justified either alone or in connection with any flood control plan.

111. Plan B provides for a similar enlargement through the Narrows by widening the banks and excavating to a depth of five feet below the low water level. The minimum cross-sectional area thus obtained is 21,500 square feet, an increase of 34 per cent. It is estimated that 37,000 cubic yards of earth and 466,000 cubic yards of rock be excavated at a total cost of $1,200,000. For a flood equal to that of March 1936 the crest stage would be reduced 4.4 feet immediately above the enlargement and 2.70 feet at Northampton. The reduction of average annual direct loss would be $13,170, if this plan alone is considered, and $1,570 if the reservoirs of the Comprehensive Plan were in operation. Since the annual carrying charge is $56,000, it is seen that Plan B is not justified either alone or in combination with any flood control plan.

112. Wells River Bar at Wells River, Vermont.- The reach of river studied extends downstream from the mouth of the Wells River for a distance of 1,600 feet. The Wells River flows in from the Vermont side about 1,300 feet below the mouth of the Ammonoosuc River. The 1936 flood slope throughout this reach and for some miles below was very flat, about 0.3 foot per mile, but immediately

above, a series of narrows caused it to increase abruptly, rising about ten feet in a distance of half a mile.

113. About 300 feet below the mouth of the Wells River, the 1927 flood deposited a gravel bar that has been increased by subsequent floods. This bar turns the force of the current towards the Vermont shore, thereby undermining the steep river bank. It is estimated that approximately 75 feet of bank has been eroded since 1927, at least half of the erosion occurring in the 1936 flood. The swift current in the latter flood carried away one house and damaged six others on the Vermont shore. In the March 1936 flood the cross-sectional area at the most restricted section of the bar was about 14,600 square feet and the maximum velocity through this section was about 8.0 feet per second. By excavating part of the bar this restricted area can be increased 35 per cent and as a result the maximum velocity can be reduced to about 5.8 feet per second and its direction changed away from the shore. It is estimated that about 77,400 cubic yards of gravel must be removed at a total cost of $31,600. This work would give a few houses incomplete protection from scouring velocities, but at a cost greater than their total valuation. Because of the flat slope throughout the reach and the steep slope above it, no appreciable reduction of stage can be expected at points upstream. Since the flood-controlling effect is negligible, this plan can not be justified as a flood-control measure.

WEST RIVER, VERMONT

114. The West River drains the eastern slope of the Green Mountains in southeastern Vermont. Its length is 52 miles and the general course of the river from its source is southeasterly to its

junction with the Connecticut River at Brattleboro, Vermont. The drainage area covers 423 square miles of rugged country. The tributary valleys are narrow with steep wooded slopes typical of the Green Mountains. The total fall of the river between Weston and Brattleboro, a distance of 45.5 miles, is 1,061 feet, giving an average slope of 23.4 feet per mile. Reference is made to West River watershed map, Plate 187, and Profile, Plate 189, in Volume 3 of the Appendix.

115. Railroads.- The Boston and Maine Railroad crosses West River just above its confluence with the Connecticut River. At one time the West River Branch of the Central Vermont Railroad served the West River area from Brattleboro to South Londonderry at mile 35. Most of this line has been abandoned, and at this time the railroad is in operation from Brattleboro to West Dummerston at mile 5.

116. Roads.- Gravel roads connect the communities in the drainage area. That section of State Route 30, between Brattleboro and Townshend is the only section of hard-surfaced road in the West River Basin. It is understood that additional improvements are planned by the State on other state roads within the watershed, including State Routes 8 and 11. The need for improved highways is growing with the increasing popularity of the area as a recreational center.

117. Commercial statistics.- From the census of 1930, the total number of farms is estimated at 760, comprising a total acreage of 126,300 with an assessed valuation of $2,706,500. For statistics on industry, the Federal Census of 1929 gives data for each of the three

counties which are, in part, drained by the West River and its tributaries. A ratio of areas is not applicable for industrial statistics, since the West River drainage area lies in those sections of the three counties in which there are no industrial centers. However, there are in the drainage area at least three woodworking establishments, one small hydroelectric development (public utility), and granite quarries at West Dummerston. Logging operations are carried on in various parts of the watershed upon a small scale.

118. Population.- The population is comparatively sparse and scattered, with no single community having a population of as much as 200. From data in the 1930 Federal Census, the population of the drainage area at the time is estimated at 5,000. This gives an average of less than twelve persons per square mile for the drainage area, as against 60.2 persons per square mile for the State of Vermont.

119. Flood losses of record.- Flood losses for 1927 and 1936 are shown in the following table:

FLOOD LOSSES - WEST RIVER

Year	Urban	Rural	Industrial	Railroad	Highway	Total
1927	0	$7,500	$10,000	$113,100	$370,400	$501,000
1936	0	2,300	9,500	0	127,200	139,000

There was one life lost in Windham, on a sidestream of the West River, during the 1936 flood. Data regarding earlier floods are largely limited to the statement of flood heights and the most important items of damage.

120. Average annual flood damage.- The West River was divided into two damage zones; the losses in each zone at the 1927 and 1936 flood stages, were they to recur today, were estimated; and the

average annual direct flood losses were computed. These values are shown in the following tabulation:

Zone No.	Description From	Description To	Index Station	Recurring Direct Flood Losses 1927	Recurring Direct Flood Losses 1936	Average Annual Direct Losses
Tr-13X	The Island Damsite	Newfane Damsite	Mile 26*	$196,000	$ 80,000	$10,400
Tr-13	Newfane Damsite	Mouth	Mile 5*	330,000	30,000	11,300
Total				$526,000	$110,000	$21,700

* Miles above mouth of West River.

121. Method of flood control.- Since by far the greatest loss from floods in the West River Valley accrues with the destruction of highway bridges and roads, protection by levees or channel improvement, even if possible, would necessarily be local in character and effect, and, therefore, would leave a large part of the valley with no protection whatever. No plan of channel correction or levee construction appears to warrant discussion here. Storage or detention reservoirs would not only benefit the reach, or reaches, of West River below the proposed reservoirs, but also would tend to reduce flood crests to a measurable degree on those reaches of the Connecticut River below the junction of West River.

122. Reservoir sites studied.- A proposed flood-control reservoir site (No. 40), located on the main stream near Newfane, is recommended and described in the Connecticut River section of this report. Two other sites studied are "The Island," located on West River about one mile above Londonderry, Vermont, and "North Landgrove", located on Orcutt Brook 3.7 miles above its junction with West River and about three miles northwest of Londonderry, Vermont. Pertinent

data for these sites are to be found in Section 4 of the Appendix.

123. Flood controlling effect of proposed reservoirs.- The reductions of the 1927 and 1936 flood peaks by the proposed reservoirs are listed in the following table:

Reservoirs	Zone No.	Index Station	Drain. Area at Ind.St. sq. mi.	Controlled Drain. A.s.m.	Stages in feet 1927 Natural	1927 Modified	1927 Reduct	1936 Natural	1936 Modified	1936 Reduction
The Island				40.9	14.8	13.4	1.4	11.8	11.0	0.8
North Landgrove	Tr-13X	Mile 26 Highway Bridge at Jamaica, Vt.	185	21.3	14.8	14.1	0.7	11.8	11.4	0.4
The Island plus North Landgrove				62.2	14.8	12.5	2.5	11.8	10.5	1.3
Newfane	Tr-13	Mile 5 Highway Bridge at W.Dummerston	375	326	23.0	7.2	15.8	19.3	8.0	11.3
Newfane plus The Island plus North Landgrove				326	23.0	7.2	15.8	19.3	7.0	12.3

124. Economic analysis of reduction of average annual direct damages by reservoirs considered.- The reductions of average annual direct damages by the West River reservoirs under consideration were computed as described in Appendix No. 2 to the Connecticut River Section of this report. The results are shown in the following table:

Reservoir	Reduction of Average Annual Direct Damage by Reservoirs Considered: Tr-13X	Tr-13	Conn. River below Mouth of West River	Total	Average Annual Cost	Ratio Direct Benefits / Cost
The Island (alone)	$5,100	$2,500	$ 15,700	$ 23,300	$ 61,300	.38
North Landgrove (alone)	3,000	1,500	8,300	12,800	36,100	.35
Newfane (alone)	0	9,000	115,600	124,600	250,900	.50
The Island (after Newfane)	5,100	0	4,000	9,100	61,300	.15
North Landgrove (after Newfane)	3,000	0	2,000	5,000	36,100	.14

The actual benefits that will accrue to a flood-control reservoir depend somewhat upon the extent of flood-control storage that is constructed prior to it, for economic or other reasons. For comparative purposes, each reservoir was considered to be the first in a system in determining the benefits shown above. On this basis, it can be seen that Newfane Reservoir, with a ratio of direct benefits to cost of 0.50, is of higher merit than either the Island or North Landgrove Reservoir, for which the ratios are 0.38 and 0.35, respectively. Therefore, Newfane should receive first consideration, and justification of the remaining two reservoirs should be dependent upon the benefits they would provide in addition to Newfane. On this basis it can be seen from the above table that their principal value would be in reducing flood damage in the Upper West River Zone. Since the annual direct benefit in this zone is less than 10 per cent of the annual cost of either reservoir, and since no other benefit is appreciable, their construction is not warranted. As shown in the Connecticut River section of this report, the drainage area controlled is the largest, and the flood control benefit extensive for Newfane Reservoir, and it is, therefore, included in the Comprehensive Plan.

PASSUMPSIC RIVER, VERMONT

125. The Passumpsic River is wholly in Vermont, and joins the Connecticut River below Fifteen Mile Falls. Its length is about 43 miles. The basin, with an area of 507 square miles, is subject to destructive floods. The topography is hilly and rocky, with narrow valleys and steep wooded slopes. The average slope of the stream is 22 feet per mile, but one of the branches, Joes Brook, has a fall of

96 feet per mile, one of the most precipitous streams in the Connecticut River Basin. There is but little natural storage and small ground-water capacity. Reference is made to map, Plate 167, and profile, Plate 168, in Volume 3 of the Appendix.

126. Tributaries.- Important tributaries of the Passumpsic River are: Joes Brook, area 58 square miles, which joins the main stream at mile 2.1 from the mouth; Sleepers River, 42 square miles, at mile 8.1; Moose River, 118 square miles, at mile 9.3; Millers Run, 56 square miles, at mile 21.1; the West Branch of the Passumpsic River, 74 square miles, at mile 22.5; and the East Branch, 17 square miles, at mile 34.4.

127. Railroads.- The Canadian Pacific Railway running northward from its connection with the Boston and Maine Railroad at Woodsville, New Hampshire, traverses the length of the basin, passing through the principal communities, and connecting with the Maine Central Railroad, which runs easterly from St. Johnsbury, Vermont, to Portland, Maine, and with the St. Johnsbury and Lake Champlain Railroad, running westerly from St. Johnsbury to a connection with the Central Vermont Railway near Lake Champlain.

128. Roads.- All communities of any importance are served by improved roads, including a considerable mileage of concrete road running north, south and west from St. Johnsbury.

129. Population.- The populations (1930 census) of the principal villages are as follows: St. Johnsbury, 7,920; Lyndonville, 1,559; West Burke, 359. The populations of the principal towns are as follows: St. Johnsbury, 9,696, Lyndon, 3,285; Danville, 1,600; Burke, 1016.

The total population of the twelve towns which practically comprise the drainage area is 19,290, or 38 per square mile on the 507 square miles of area.

130. Industry.- The principal activity in the basin is agriculture. The 1930 census states that there are 1,397 farms in the 12 towns comprising the basin, totaling 205,597 acres and valued at $6,669,245. The chief industries are in iron and steel, clay, glass and stone, and wood-working plants. The value of annual output of manufactured goods, according to the latest census, is set at $9,582,187, and annual wages amount to about $2,000,000.

131. Power.- Small mills on the Passumpsic River and Joes Brook utilize a part of the available water power. More has been developed by the Twin State Gas and Electric Company, which operates five plants on the Passumpsic River between miles 5 and 17; the Lyndonville Electric Company two plants at miles 16 and 18 on the Passumpsic River; and the Green Mountain Power Corporation, with one site on Joes Brook. This company is now a part of the New England Power Association.

132. Flood control.- The flood of 1927 caused the greatest loss ever sustained, the total reported being $2,584,000, of which over one-half was road and bridges. Many severe storms previous to 1927 would undoubtedly cause as much loss under present conditions. The principal damage centers are St. Johnsbury, Lyndonville and Barnet. The flood loss in 1936 was reported at $72,000, of which $38,000 was industrial. Adequate protection is obtainable by the construction of storage reservoirs, and benefits will also accrue to reaches on the Connecticut River. A number of sites have been investigated in the

past for power and flood control combined. Of these, four sites were selected for further study in connection with this report. East Haven - No. 18, Lyndon Center - No. 21A, and Victory - No. 22, are recommended as units in the Comprehensive Plan for the Connecticut River, and are fully described elsewhere. Lyndonville - No. 20, was considered as an alternate for East Haven, and pertinent data are given in Section 4.

SUMMARY AND DISCUSSION

133. Need for flood control.- The Connecticut Valley has been subject to frequent and severe floods, and flood control is of paramount importance for the preservation of existing values, the stability of present development, and the social security of the inhabitants. The distribution of these floods over the valley is not uniform. One flood may be relatively greater on the tributaries, whereas another may be more damaging to the lower river. The great flood of November, 1927 produced record stages on a number of tributaries, and on the upper river, whereas the flood of 1936 produced record stages and maximum losses on the lower river at the larger centers of population and industry. Direct losses have been estimated at $15,526,000 from the flood of 1927 and $34,500,000 from the flood of 1936. In the 1927 flood twenty-one lives were lost, and in the 1936 flood eleven lives were lost. Thorough study and analysis indicate that indirect related losses amounted to at least 94.5 per cent of the 1936 direct losses, in addition to which there was depreciation of property values conservatively estimated to have been not less that $74,857,000. Aside from these losses which are susceptible to a money evaluation, there were extensive intangible losses of importance. The heavy losses experienced

have developed a feeling of insecurity and restlessness and it appears probable that if confidence is not restored by the initiation of a comprehensive plan for protection, industries of value may move from the valley. An important result of protection, which has not been taken account of in its economic evaluation, is the potential increase in property values because of their availability for a higher and more remunerative use if relieved of recurring flood menace.

134. Relative effectiveness of flood control measures.- The protection of the upper part of the valley by dikes is not feasible, and it is estimated that the protection of the valley south from the northern boundary of Massachusetts by a system of dikes would cost about $43,000,000, or about 90 per cent of the estimated cost of the proposed Comprehensive Plan. The proposed dikes alone would afford protection about one-half as effective as that afforded by the proposed Comprehensive Plan. They would increase flood stages and, consequently, the hazard at the major flood loss centers in Massachusetts and Connecticut. Reservoirs, by holding flood waters near to their sources, afford protection to all of the valley below them so that their effect is widespread. They reduce flood stages, eliminate the small, and many of the moderate floods, and materially reduce the damage from large floods. They will not afford, however, complete protection against the larger floods. Channel improvements may be effective, but to materially reduce flood heights they are relatively expensive. In the most promising cases on the Connecticut River, their justification disappears when they are considered in combination with reservoirs. A comprehensive plan for flood control in the

Connecticut River Valley should be based therefore on reservoirs, with dikes where justified for complete local protection of areas of high value. Such a plan utilizes the most economical and best located of the available reservoir sites, supplementing the protection they afford by dikes where necessary. It protects the tributary valleys which have been developed substantially and are seriously exposed to flood damage, and the main river valley below Wells River.

135. The Proposed Plan.- A Comprehensive Plan is proposed consisting of twenty reservoirs, distributed among fourteen of the tributaries, and dikes for the protection of seven cities and towns as follows:

RESERVOIRS

Ident. No.	Name	Stream and State	
	Basic List		
18A	East Haven	Passumpsic River	Vt.
21A	Lynden Center	Millers Run (Passumpsic)	Vt.
22A	Victory	Moose River (Passumpsic)	Vt.
50	Harvey Lake	Stevens River	Vt.
24A	Bethlehem Junction	Ammonoosuc River	N. H.
27A	Groton Pond	Wells River	Vt.
28A	South Branch	South Branch (Waits)	Vt.
48	Union Village	Ompompanoosuc River	Vt.
29A	Gaysville	White River	Vt.
30A	Ayers Brook	Ayers Brook (White)	Vt.
49A	South Tunbridge	First Branch (White)	Vt.
63	North Hartland	Ottauquechee River	Vt.
64A	Claremont	Sugar River	N. H.
55A	No. Springfield	Black River	Vt.
40A	Newfane	West River	Vt.
57A	Surry Mountain	Ashuelot River	N. H.
59	Lower Naukeag	Millers River	Mass.
65	Birch Hill	Millers River	Mass.
62A	Tully	Tully River (Millers)	Mass.
47	Knightville	Westfield River	Mass.

DIKES

Hartford, Connecticut
East Hartford, Connecticut
Springfield, Massachusetts
West Springfield, Massachusetts
Chicopee, Massachusetts
Holyoke, Massachusetts
Northampton, Massachusetts

In addition to the reservoirs included in the proposed Comprehensive Plan, there are additional sites of merit which might be utilized in case local considerations should prevent the development of all the selected sites, or in case local interests should desire to develop conservation storage to a maximum degree. Data on the following sites are presented in this report.

ALTERNATE RESERVOIRS

Ident. No.	Name	Stream and State
26	Gale River	Gale River (Ammonoosuc)... N. H.
69	Bath	Ammonoosuc River .... N. H.
70	Centerville	White River .... Vt.
66	West Canaan	Mascoma River .... N. H.
72	Mascoma Lake	Mascoma River .... N. H.
53A	Stocker Pond	Stocker Brook (Sugar) .... N. H.
36	Ludlow	Black River .... Vt.
74	Perkinsville	Black River .... Vt.
60	Hydeville	Millers River .... Mass.
61A	Priest Pond	Priest Brook (Millers) ... Mass.

136. Estimated costs.- The total cost of the plan is estimated at $47,000,000, of which $32,822,000 will be the cost to the United States for construction and excess cost of lands and damages, as provided by the Flood Control Act of 1936, and $14,178,000 will be the cost to local interests for lands and damages, and for pumping plants and drainage. The estimated cost of the reservoirs to the United States is $24,260,000, and to local interests $10,575,000 (See Table 19).

The estimated cost of the dikes to the United States is $8,882,000, and to local interests $815,000 for lands and damages, and $2,788,000 for pumping plants and drainage (See Table 25). The total annual cost is estimated at $2,729,000, of which $1,579,200 is the cost to the United States, and $1,149,800 is the cost to local interests. The estimated annual cost of the reservoirs to the United States is $1,169,500, and to local interests $818,200; and the annual cost of dikes is $409,700 to the United States and $331,600 to local interests. The estimated annual cost to local interests for maintenance and operation of the reservoirs is $200,000, and for dikes $86,600, which amounts are included in the total annual costs stated above.

137. Benefits.- The direct benefits are ascertainable from the recurring and preventable direct losses. Indirect collateral benefits vary with different types of losses but a fair average is 94.5 per cent of the direct losses (See Paragraph 48). The depreciation sustained by property as the result of flooding and the possibility of its recurrence has been studied utilizing all available sources of information, and has been found to be very heavy. It has no direct relation to the direct losses, is not a part of or included within the estimates of direct and indirect losses and has been estimated from a study of the losses in the various zones. The total average annual benefits are estimated to be $5,268,000, of which $2,066,000 are the benefits from the reservoirs, and $3,202,000 the benefits from the dikes. The benefits from the reservoirs are composed of direct benefits amounting to $791,300, indirect benefits in the amount of $746,000 and restoration of depreciation amounting to $526,000. Of the benefits from the reservoirs $663,000 will be realized on the tributaries, and $1,402,000

on the main river. The benefits from the dikes are composed of direct benefits amounting to $62,400, indirect benefits amounting to $68,400, and restoration of depreciation amounting to $3,071,200. It will be noted that the indirect benefits from the dikes exceed the direct benefits due to the fact that the dikes protect only areas of concentrated high values. (See Paragraph 96.) It is estimated that if the proposed Comprehensive Plan herein had been in operation during the 1927 and 1936 floods, the saving of direct and indirect losses would have amounted to approximately $68,000,000, and the avoidance of depreciation of property would have approximated $59,880,000 in 1936 and have been a substantial item in 1927.

138. Ratio of benefits to costs.- On the basis of foregoing costs the ratio of annual average benefits to annual costs is 1.04 for the reservoirs, 4.32 for the dikes, and 1.93 for the entire plan. It is considered, however, that these ratios are low for the reasons stated in the following paragraphs.

139. Adjustment of costs to agree with present conditions.- Fixed charges in the estimates of annual costs have been computed on the basis of an interest rate of 4 per cent for Federal costs and 5 per cent for costs to local interests. Interest rates paid by the United States on long term loans have been for several years less than 3 per cent, and those with an intimate knowledge of financial matters who will hazard an estimate as to the future, believe that they will not exceed 3 per cent for a period of years. The states affected by the proposed plan customarily borrow money at rates lower than 3 per cent, and it is considered probable that they may finance the proposed expenditures for as little as 2-1/2 per cent. It is believed therefore

that for the purpose of comparing costs and benefits, the costs should be computed at not to exceed 3 per cent. Estimates of costs of the reservoirs provide between 5 and 8 per cent for anticipated increase in prices during the construction of the project. In comparing costs with benefits, this contingency item should be subtracted from the costs to make them approximate the same period of time as the losses, and comparable with benefits. The estimates for the individual reservoirs contain a construction contingency item of from 12 to 15 per cent, and while this percentage is necessary for individual reservoirs, it is considered to be unlikely that the construction of every reservoir will absorb the entire allowance. It is thought that the total construction contingencies on the entire group should amount to about one-half of the total on the individual reservoirs. Bringing the costs and losses to occurrence as of the same time, basing the financing on an interest rate of 3 per cent, and charging the project with reasonable overall contingencies, the ratio of benefits to costs for the reservoirs becomes 1.37, for the dikes 5.20, and for the entire plan 2.47. The estimates provide for the amortization of the entire investment in fifty years, so that thereafter the expense will be limited to the cost of operation and maintenance.

140. Benefits from conservation.- Three of the sites, Gaysville, Knightville and Newfane, are suitable for flood control and the development of power at the site. At Gaysville and Newfane, and eight additional sites, development for power by providing storage, additional to that required for flood control, to be released for the benefit of downstream power plants is justified. Several sites are suitable for

development for recreation in addition to flood control by providing lakes for summer vacation use. The release of water stored and held into low-water periods will be of some benefit also from the standpoint of sanitation in the lower river, and of considerable benefit if all suitable sites should be developed for conservation and flood control. The proposed plan facilitates the development of conservation values and does not destroy these values at any site. Conservation storage for the benefit of hydroelectric power generation, the control of stream pollution and recreation can be developed at the expense of local interests, and generally for much less than the cost of an equivalent development for conservation only.

141. Unevaluated benefits.- In addition to the evaluated benefits resulting from the elimination by reservoirs and dikes of direct and indirect losses and the depreciation of previously existing property values, there are important and unevaluated benefits. The provision of flood control storage will materially assist in the development on a cooperative basis of storage at several sites for conservation purposes and particularly for the benefit of power generation. The provision of recreation lakes should attract summer visitors and more than offset values destroyed by flowing agricultural lands at the sites where lakes are provided. The estimates provide for amortization in fifty years, whereas the value of the improvements at the end of this period should be equal and may easily exceed their value under present conditions. Areas now frequently flooded and of low value will be protected and may become highly valuable for industrial purposes, or similar preferred uses. It may be anticipated that the industrial use of the valley will continue to increase with the increasing values and

consequently increasing benefits as a result of adequate flood protection. Experience definitely associates high maintenance costs for the navigable channel below Hartford with large floods. The flood control plan, by reducing flood magnitudes, should reduce the cost of maintaining this channel. The value of the reduction in maintenance costs cannot be computed and will be small in comparison with the annual cost of the Comprehensive Plan. A consideration of the benefits stated in this paragraph indicates total benefits substantially in excess of those evaluated in paragraph 137.

142. Necessity for maintaining flood control capacity.- In the Connecticut River Valley, where a site is developed for flood control and conservation, the conservation use should not encroach materially upon the use of storage capacity provided for flood control. While it is recognized that floods occur more frequently in some months than in others, it also must be recognized that they have occurred in dangerous proportions during every month, and that there is always the possibility that a sudden and severestorm may occur on a small watershed and produce a damaging flood on that particular tributary. This is considered one of the problems to be faced in the control of the smaller drainage areas, and its importance diminishes as the area to be controlled increases. It is believed therefore that the dual use of the same storage capacity for flood control and conservation, by regulating the volume available for flood control with the month or season is hazardous unless the diversion of storage capacity from flood control to conservation uses applies only to minor portions of the total flood control storage at each site.

143. <u>The West and Passumpsic Rivers.</u>- Flood control, to the extent that it is economically justified, will be provided on the West and Passumpsic Rivers by reservoirs which are parts of the Comprehensive Plan for the protection of the entire valley.

144. Local cooperation .- The need for the control of floods is keenly felt throughout the Connecticut Valley, and there is a general and active interest in obtaining protection, particularly for populous centers where the heaviest losses occurred in the 1936 flood. It is believed that local interests are substantially in accord with the recommended plan. Objections to the general plan for flood protection proposed herein, so far as they have been determined or reported, are local in nature and restricted to a limited number of sites in the State of Vermont. It is believed that these objections can be satisfactorily overcome. The various states have appointed compact commissions which have met repeatedly, and have arrived at a compact agreement for submission to their respective legislatures and to the Congress of the United States for approval and ratification. It is believed that the means for complying with all requirements of local cooperation for the reservoirs will be provided before the end of the current fiscal year. The representatives of all of the cities and towns for which dikes are recommended have expressed approval of the proposed plans. The officials of the larger cities have stated that they are ready to meet the conditions of local cooperation as soon as the work is approved for construction and Federal funds are provided. Responsible officials of several of the smaller localities have stated that they are without the means to proceed at present, but desire to start the work as soon as they can meet the requirements for cooperation. At certain

localities plans are being studied for combining protective dikes with other improvements and it appears desirable that the federal flood control projects be modified in order to participate in these projects, provided federal expenditures are not increased and full flood protection values are secured.

CONCLUSION

145. The flood menace in the Connecticut Valley is serious, and the need is urgent for relief measures to prevent serious losses, preserve existing values, restore values that existed prior to the floods of 1927 and 1936, and maintain economic and social stability and security. The plan for flood control should be comprehensive and provide protection for the tributaries as well as the main river, to the extent that each is justified. Future storage for the benefit of hydroelectric power, recreation or other conservation use can be developed advantageously in connection with the flood control plan. The Comprehensive Plan described and proposed herein is economically justified and will provide a satisfactory measure of protection.

RECOMMENDATION

146. It is recommended that the existing project for the control of floods in the Connecticut River Valley be revised to include the Comprehensive Plan proposed in this report, consisting of twenty reservoirs, and dikes at seven localities, at an estimated cost of $47,000,000, of which $32,822,000 is the estimated cost to the United States for construction and the excess cost of lands and damages, as provided by the Flood Control Act of 1936, and $14,178,000 is the estimated cost to local interests for lands, damages, pumping plants and drainage; and that

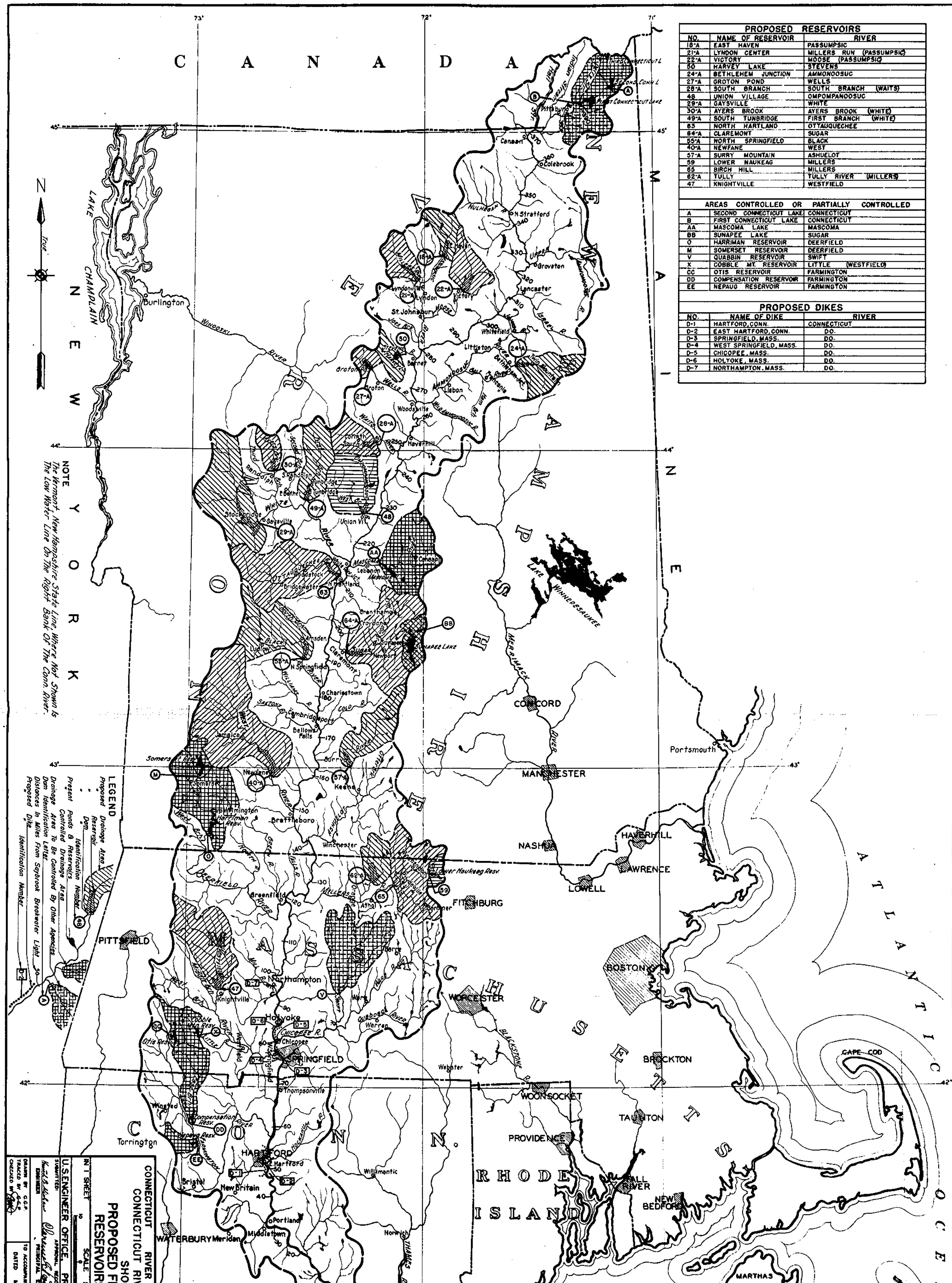
the Secretary of War be authorized to substitute alternate reservoir sites for any of the twenty sites recommended, and to make modifications in the plans proposed for the dikes and enter into cooperative projects with the communities to be protected by them, provided that the total cost to the United States shall not exceed $24,260,000 for the reservoirs, and $8,562,000 for the dikes, and that the cost to the United States for each locality protected by dikes shall not exceed that stated in this report.

Mason J. Young,
Lieut. Col., Corps of Engineers,
District Engineer.

Inclosures (separate):

Appendix:

Volume 1 -	Section 1	Hydrology and Meteorology
	Section 2	Flood Losses - Benefits
	Section 3	Conservation - Power and Recreation
Volume 2 -	Section 4	Reservoirs - Details and Estimates
	Section 5	Dikes - Details and Estimates
	Section 6	Channel Improvements
Volume 3 -	Section 7	Maps, Plans and Profiles



PROPOSED RESERVOIRS

NO.	NAME OF RESERVOIR	RIVER
18-A	EAST HAVEN	PASSUMPSIC
21-A	LYNDON CENTER	MILLERS RUN (PASSUMPSIC)
22-A	VICTORY	MOOSE (PASSUMPSIC)
50	HARVEY LAKE	STEVENS
24-A	BETHLEHEM JUNCTION	AMMONOOSUC
27-A	GROTON POND	WELLS
28-A	SOUTH BRANCH	SOUTH BRANCH (WAITS)
48	UNION VILLAGE	OMPOMPANOOSUC
29-A	GAYSVILLE	WHITE
30-A	AYERS BROOK	AYERS BROOK (WHITE)
49-A	SOUTH TUNBRIDGE	FIRST BRANCH (WHITE)
63	NORTH HARTLAND	OTTAUQUECHEE
64-A	CLAREMONT	SUGAR
55-A	NORTH SPRINGFIELD	BLACK
40-A	NEWFANE	WEST
57-A	SURRY MOUNTAIN	ASHUELOT
59	LOWER NAUKEAG	MILLERS
65	BIRCH HILL	MILLERS
62-A	TULLY	TULLY RIVER (MILLERS)
47	KNIGHTVILLE	WESTFIELD

AREAS CONTROLLED OR PARTIALLY CONTROLLED

A	SECOND CONNECTICUT LAKE	CONNECTICUT
B	FIRST CONNECTICUT LAKE	CONNECTICUT
AA	MASCOMA LAKE	MASCOMA
BB	SUNAPEE LAKE	SUGAR
O	HARRIMAN RESERVOIR	DEERFIELD
M	SOMERSET RESERVOIR	DEERFIELD
V	QUABBIN RESERVOIR	SWIFT
X	COBBLE MT. RESERVOIR	LITTLE (WESTFIELD)
CC	OTIS RESERVOIR	FARMINGTON
DD	COMPENSATION RESERVOIR	FARMINGTON
EE	NEPAUG RESERVOIR	FARMINGTON

PROPOSED DIKES

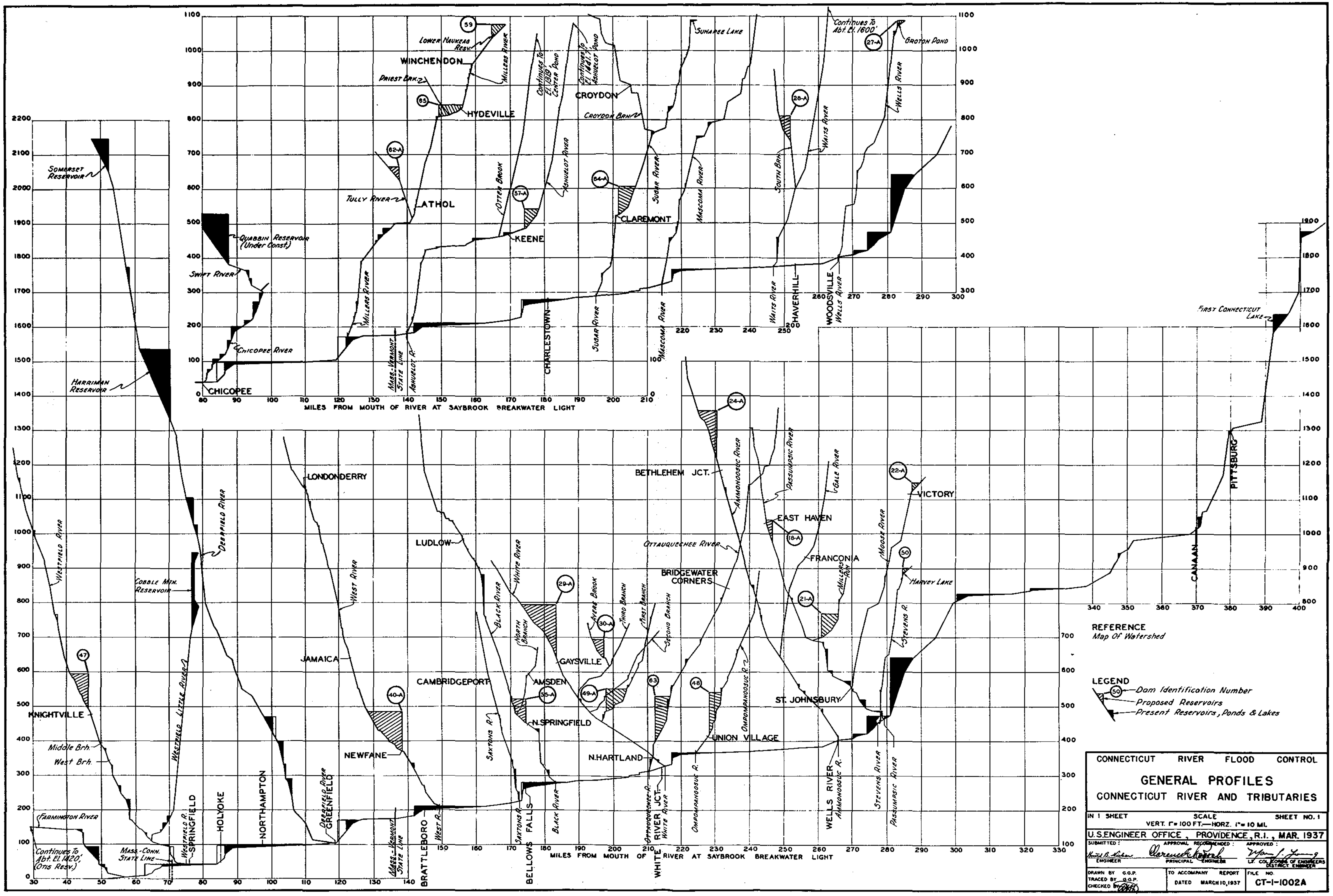
NO.	NAME OF DIKE	RIVER
D-1	HARTFORD, CONN.	CONNECTICUT
D-2	EAST HARTFORD, CONN.	DO.
D-3	SPRINGFIELD, MASS.	DO.
D-4	WEST SPRINGFIELD, MASS.	DO.
D-5	CHICOPEE, MASS.	DO.
D-6	HOLYOKE, MASS.	DO.
D-7	NORTHAMPTON, MASS.	DO.

CONNECTICUT RIVER FLOOD CONTROL
CONNECTICUT RIVER WATERSHED
SHOWING
PROPOSED FLOOD CONTROL
RESERVOIRS AND DIKES

IN 1 SHEET — SHEET NO. 1
SCALE 1:500,000

U.S. ENGINEER OFFICE, PROVIDENCE, R.I. MAR. 1937

TO ACCOMPANY REPORT DATED MARCH 10, 1937
FILE NO. CT-1-1001B



CONNECTICUT RIVER FLOOD CONTROL

GENERAL PROFILES

CONNECTICUT RIVER AND TRIBUTARIES

IN 1 SHEET — SCALE VERT. 1" = 100 FT. — HORZ. 1" = 10 MI. — SHEET NO. 1

U.S. ENGINEER OFFICE, PROVIDENCE, R.I., MAR. 1937

SUBMITTED: ENGINEER — APPROVAL RECOMMENDED: PRINCIPAL ENGINEER — APPROVED: LT. COL. CORPS OF ENGINEERS, DISTRICT ENGINEER

DRAWN BY G.G.P. TRACED BY G.G.P. CHECKED BY

TO ACCOMPANY REPORT DATED MARCH 10, 1937

FILE NO. CT-1-1002A

SEC. 4 - PLATE NO. II